Igneous and Metamorphic Rocks

Sequoia and Kings Canyon National Parks California

California Division of Mines

Special Report 53

COVER—The high Sierra from Kings Canyon Overlook,
Sequoia National Park.
Photo by Mary R. Hill.

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IGNEOUS AND METAMORPHIC ROCKS
OF PARTS OF
SEQUOIA AND KINGS CANYON NATIONAL PARKS, CALIFORNIA

By DONALD C. ROSS

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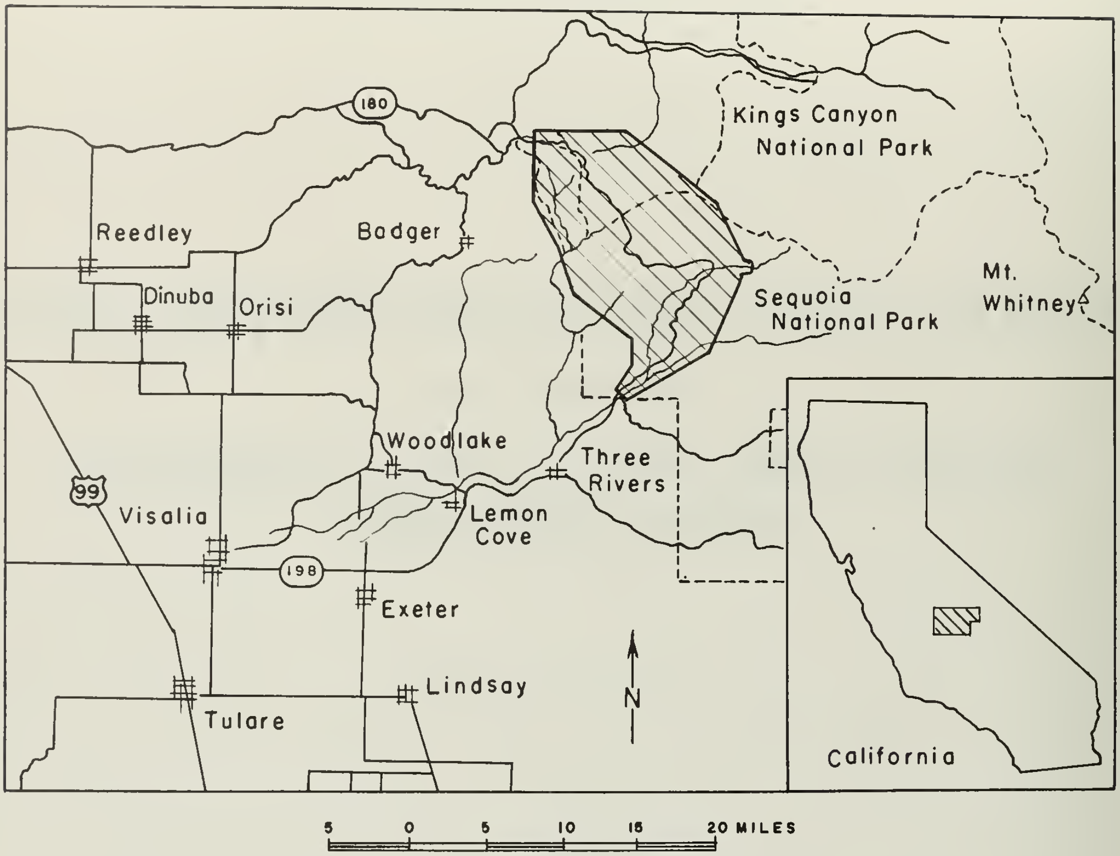

INDEX MAP OF SEQUOIA AREA

FIGURE 1.

IGNEOUS AND METAMORPHIC ROCKS OF PARTS OF SEQUOIA AND KINGS CANYON NATIONAL PARKS, CALIFORNIA

By Donald C. Ross *

OUTLINE OF REPORT

ABSTRACT

The area described in this report includes about 150 square miles on the west slope of the Sierra Nevada in Tulare County, California. Approximately 30 square miles of this area is underlain by elongated roof pendants of metamorphic rocks that dip steeply and strike northwest. Two of the major metamorphic bodies are predominantly metasedimentary; the third probably contains some leucocratic metavolcanic rocks. The remainder of the area is underlain by 13 mappable plutonic types ranging in composition from gabbro to alaskite.

Inter-pluton contacts are generally sharp. Contacts between plutonic rocks and metamorphic rocks are either sharp or show injection zones with varying amounts of assimilation. The abundance of lit-par-lit zones at lower altitudes may reflect the nearness of the pendant roots.

The magma was emplaced in part by assimilation and stoping, but no evidence was found in support of forcible injection. The small amount of wall rock, however, precludes conclusions as to the dominant intrusion mechanism.

The relative age of the various plutons is commonly difficult if not impossible to determine, but one well established sequence involves four of the most important units. The four bodies show an increase in silicity with a decrease in age, and also a concentric pattern with each succeeding younger body intruding the core of the older pluton.

The age of the metamorphic rocks was not determined; the plutonic rocks are assumed to be Jurassic-Cretaceous on the basis of dating elsewhere in the Sierra Nevada and in associated plutonic areas.

Xenoliths are rare in the plutonic rocks in general, but are locally abundant. Some rhythmic hornblende layering is probably due to alternate settling of hornblende crystals and sweeping by convection currents. The origin of most of the inclusions is unknown, but some have formed by the recrystallization of metamorphic rocks and gabbro.

INTRODUCTION

Recent work has revealed the complexity of many supposed homogeneous batholithic bodies in the Sierra Nevada. The present study of thirteen plutonic rock units mapped in 150 square miles of Tulare County is further proof of the intrusive diversity of at least a part of the Sierra Nevada batholith.

Geography and Features of Sequoia National Park. The area described in this report is in the western part of Sequoia National Park and adjacent parts of the Kings Canyon National Park and Sequoia National Forest. The Ash Mountain entrance to Sequoia National Park, in the southwest corner of the area, is 27 miles northeast of Visalia, California.

California State Highway 198 connects Visalia with the Park, and a well maintained asphalt road (Generals Highway) crosses the west end of the Park and connects with California Highway 180 near the northwest corner of the area. Branch roads of poorer quality extend to Crystal Cave, Big Meadow, and Redwood Canyon. The many Park Service and Forest Service trails aid travel in the higher country and provide the only access to the lower, brush-covered slopes.

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* Paper adapted from a thesis submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Geology, University of California, Los Angeles. Manuscript submitted for publication November 1953.

PHOTO 1. Moro Rock. A large dome in the Giant Forest pluton as seen from the south on the Middle Fork trail.

Sequoia National Park is the second oldest National Park in the country; its main attraction is the giant redwood tree *Sequoia gigantea. Sequoia gigantea* is restricted to isolated, scattered groves on the intermediate slopes of the western Sierra Nevada. Sequoia National Park contains a number of these groves, the largest of which is Giant Forest with well over 3,000 trees, many approaching 300 feet in height and 30 feet in diameter. The other major groves are Muir Grove, Lost Grove, and Redwood Mountain, as well as others outside the area of this report.

An interesting book (Matthes, 1950) has been published on the geology of Sequoia National Park based on the work of François E. Matthes, who spent much of his life in the Sierra Nevada. The many photographs in the book, with only a small amount of printed text, make it particularly interesting to persons who have not had geologic training. Matthes specialized in the study of glacial action, and his book is concerned chiefly with the work of glaciers and other erosional and weathering processes that produced the present landforms of th Sequoia area. Most visitors to Sequoia will not have a opportunity to visit the High Sierra country wher Matthes did most of his work, but some of the photos i the book are from easily accessible points within the are of this report, and the area around Heather Lake an Pear Lake shows ample evidence of the work of glaciers These lakes are in glacial cirques, and rock surfaces tha have been polished and striated by glaciers can be see at both lakes.

PHOTO 2. Exfoliation in the Giant Forest pluton as seen from the Generals Highway south of Dorst camp.

Several caverns occur in the marble in Sequoia National Park. Crystal Cave is the best known, and tour are conducted through it by the Park Service. Thoug Crystal Cave is small, it presents nearly all the feature of larger caverns and is a worthwhile part of a visit t Sequoia. An informative booklet (Oberhansley, 1946 describes the cave and the formation of caverns.

Large, massive, resistant domes of plutonic rock ar found throughout the Sierra Nevada. Moro Rock is suc a dome. Its crest is easily reached by means of a ston stairway, where one may view the spectacular Kawea River basin, and the high peaks of Kaweah ridge. Othe similar, but somewhat less impressive domes are Littl Baldy, Big Baldy Ridge, Beetle Rock, and Sunset Roc (the latter two in the Giant Forest area). All are easil accessible by trails. These domes are characteristicall eroded into thick shells, to give the appearance of th layers of an onion partially peeled. The formation o these shells is not fully understood, but the process an possible causes are discussed by Matthes (1933) in hi very interesting account of the history of Yosemit Valley. Smaller "pilot models" of this process, know as exfoliation, can be seen in roadcuts along the General Highway.

The country around the small lakes in the northeastern part of the area can be reached by trails from Giant Forest and the Generals Highway and provides excellent country for short camping trips. Jennie Lake, Twi Lakes, Pear Lake, and others are only a half-day tri from roads for a somewhat experienced hiker, and provide an opportunity for a kind of relaxation that is not possible around the more populous Giant Forest area. Almost all the trails north and east of the General Highway above Giant Forest provide excellent hiking

Giant Forest Village, the largest populated area in th park, contains most of the facilities of a small town. Many cabins and public campgrounds are located nea the Village. Ash Mountain Park Headquarters is th permanent main headquarters for Sequoia National Park.

Acknowledgments. The writer wishes to acknowledge the aid of Professor K. DeP. Watson, of the staff o the University of California at Los Angeles, who provided innumerable helpful suggestions in the writing o the thesis that provided the basis for this report. Th photomicrographs were taken by A. C. Daley. The 27 excellent thin sections used in the petrographic study fo this report were made by John De Grosse.

METAMORPHIC ROCKS

About 30 square miles of the area of this report i underlain by metamorphic rocks. The three largest masses, completely surrounded by igneous rocks, are roo pendants. They have a general orientation that parallel the attitude of known roof rocks to the north and west

Regular, persistent layers of differing mineralogical composition in the schistose rocks of the largest metamorphic body, as well as the interlayering of the schists with marble and quartzite suggests that metamorphic layering is a reflection of sedimentary bedding. Schistosity is essentially parallel to the metamorphic layering.

The metamorphic body of Redwood Mountain is a sequence of metasedimentary rocks similar to the larger mass to the south. The most easterly pendant body probably contains a large amount of silicic metavolcanic rocks and is notably lacking in quartzite and marble. The remaining small metamorphic bodies are either root portions of roof pendants or large xenoliths.

No fossils were found in the area covered by this report, but fossiliferous rocks are known to be about 15 miles to the southeast, at Mineral King, where Durrell (1940) collected fossils that were dated as Upper Triassic. The metamorphic rocks are definitely older than the plutonic intrusives, as the intrusive rocks truncate the metamorphic ones and have caused contact metamorphism within them.

In the following descriptions, modifying mineral names are applied to metamorphic rock names. The modifiers are listed in order of increasing abundance of the minerals.

Mica-Feldspar-Quartz Schist. Schist is the most common of the metasedimentary rocks and is most abundant in the western part of the largest metamorphic mass, the Redwood Mountain body, and in some of the large xenoliths. The rocks are dark gray to black on fresh surfaces, but have a distinctive reddish-brown weathered surface. The reddish-brown color is commonly reflected in the soil adjacent to schist outcrops.

An approximate average composition of the schists is 25 percent potash feldspar and intermediate plagioclase, 25 percent biotite, and 35 percent quartz. The remaining 15 percent is muscovite, epidote in the more calcareous schists, magnetite, zircon, apatite, garnet and rarely andalusite. The parent rocks were probably shales, argillaceous siltstones, and fine-grained sandstones in an intermixed sequence. An alternation of micaceous-feldspathic and quartzose layers is common and the layers range in thickness from a fraction of a millimeter up to 5 mm.

Quartzite. Fine-grained, massive quartzite, ranging from cloudy white to dark gray in color, is second to the schist in abundance and is most common in the southeastern portion of the largest pendant. Resistant quartzite beds form prominent narrow ridges on both sides of the Middle Fork of the Kaweah River near Hospital Rock; the local name Devil's Rockpile is applied to an area of blocky quartzite rubble from the ridge just north of the Hospital Rock Camp. The most common type of quartzite is predominantly quartz with subordinant amounts of feldspar and mica. Small amounts of diopside are also present, as are the common accessory minerals apatite, magnetite, and zircon. The parent rock of the quartzite was sandstone or chert with some argillaceous and calcareous impurities.

Calcareous Metamorphic Rocks. Calcareous rocks—in particular, marble—are abundant in a band trending northwest through the largest pendant. The most prominent outcrops of the band are in the canyon of the Marble Fork of the Kaweah River, along Paradise Ridge, and near Crystal Cave. Smaller isolated marble and calc-hornfels masses are found along Generals Highway east of the Ash Mountain Park Headquarters. The fine- to coarse-grained marble is snow white to dark gray in color, much of it is banded, and the alternating gray and white layers probably reflect original bedding. A great variety of calc-silicate minerals has been developed where impurities were present in the marble, or where material has been added from the plutonic rocks. The calc-silicate materials are commonly pod-like and discontinuous, but in some localities well-layered plagioclase-pyroxene hornfels probably reflects original composition and bedding. The calc-silicate minerals are best developed in the isolated calcareous bodies east of the Ash Mountain Park Headquarters and around the Barrington tungsten mine on the North Fork of the Kaweah River. The most common minerals are calcite, pyroxene of the diopside-hedenbergite series, garnet of the grossularite-andradite series, wollastonite, idocrase, quartz, plagioclase, epidote, hornblende, and biotite. Scheelite is also found locally in the calcareous rocks.

The pure marble was undoubtedly derived from limestone, and argillaceous, siliceous, and dolomitic impurities probably account for the well-layered calc-hornfels. The variance of composition of many adjacent, thin layers and the parallelism of these layers to the schistosity of the associated rocks suggests that the calc-silicate minerals represent the reconstitution of impure calcareous rocks. The irregular pod-like occurrences of calc-silicate minerals as well as occurrences at contacts between marble and igneous rocks can best be explained by the addition of magmatic material. The unaltered condition of the marble at some contacts, even where it is engulfed in plutonic rocks, demonstrates that magmatic material was not added in all places.

Amphibolite and Amphibole Schist. Amphibolite and amphibole schist are locally abundant north of Amphitheater Point, and less common as lenses in the schist and quartzite elsewhere in the roof pendants. The amphibolitic rocks are dark green, fine to medium grained, and generally somewhat schistose. Hornblende and intermediate plagioclase are the principal constituents, but some specimens are as much as 40 percent diopside. Biotite, quartz, and clinozoisite are less abundant; magnetite, titanite, apatite, zircon, pyrite, and rutile (?) are present as accessory minerals.

The parentage of the amphibolitic rocks is in doubt. One specimen from a layer of schist associated with the belt of amphibolite north of Amphitheater Point has a relict pyroclastic texture, and another specimen has relict quartz and feldspar phenocrysts in a recrystallized groundmass (photos 23, 24). These two specimens suggest the amphibolite is an altered volcanic rock. Directly west of the amphibolite, however, is a belt of marble. The proximity of calcareous rocks and the presence of diopside in some of the amphibolites also suggests a possible calcareous parentage for the amphibolites. It is well established that amphibolites can originate either by the metasomatism of carbonate sediments or by the reconstitution of basic igneous rocks (Adams, 1909; Engel and Engel, 1951; Poldervaart, 1953). The present study did not reveal sufficient evidence to choose between the two possible modes of origin of the amphibolitic rocks.

Metavolcanic Rocks. Rocks with relict volcanic or tuffaceous textures are rare in the roof pendants. Some of the hornfels and schist of the easternmost large roof pendant have affinities with volcanic rocks and will be considered as possible metavolcanic rock.

North of Amphitheater Point a small amount of metadacite is present. The rock has a blastoporphyritic texture, with plagioclase, quartz, and hornblende phenocrysts. The square cross-section of the quartz phenocrysts is suggestive of a volcanic origin. Associated specimens with clastic quartz grains suggest a tuff or tuffaceous sediment.

Cream-colored, fine-grained, massive metarhyolite (or metarhyolite tuff) is recognizable locally in the easternmost roof pendant. Associated with it is some light-colored hornfels with only hints of relict phenocrysts, or possibly relict clastic grains. Mineral proportions vary, but an average is 30 percent each of oligoclase-andesine, potash feldspar, and quartz, and 10 percent biotite. The chemical composition of the average compares favorably with common rhyolite, but could also represent an arkosic sediment. If the leucocratic hornfels is a metasediment, it is markedly dissimilar to the metasedimentary rocks of the other pendants. The scarcity of calcareous rocks, quartzite, and thinly banded mica schist in the eastern pendant suggests that the body may be chiefly a sequence of metavolcanic rocks.

Interpretation of Metamorphism. Well-developed schistosity in most of the metamorphic rocks, as well as the development of augen structure locally, indicates shearing. Almandine garnet was found at only one locality; the remainder of the metamorphic rocks are representatives of the biotite zone of Harker (1950).

Some of the schist and marble shows features characteristic of thermal or contact metamorphism. The development of andalusite, diopside, wollastonite, grossularite, and idocrase is characteristic of contact deposits. The growth of poikiloblastic muscovite crystals in a random orientation in some of the schists (photo 21) is suggestive of a second period of metamorphism superimposed on the regional metamorphism that formed the schists. The formation of the large, randomly oriented muscovite crystals could be related to the thermal metamorphism or to some later hydrothermal conditions.

ASH MOUNTAIN COMPLEX

In the vicinity of the Ash Mountain Park headquarters four rock types have been mapped together as the Ash Mountain complex. The complex covers about 1 square mile within the mapped area and extends west and south for an undetermined distance. The major rock type of the complex is a dark-gray, fine-grained rock of quartz diorite composition which is intruded by a fine-grained, lighter gray rock also of quartz diorite composition. The two fine-grained types are markedly dissimilar to the plutonic types in the mapped area, and are possibly altered metamorphic rocks. Smaller amounts of quartz diorite, resembling material of the Giant Forest pluton, and granite of the Cactus Point pluton, are present within the complex.

Petrography. The dark-gray, fine-grained rock contains approximately 60 percent intermediate andesine, and traces of potash feldspar. Quartz composes 15 percent of the average specimen as does brown biotite. The remaining 10 percent of the rock is green hornblend Some hornblende crystals are sieve-like and have structure resembling schiller structure. Apatite, sphen zircon, and magnetite are also present. The averag grain size of the specimens is 0.2 mm and the crysta are anhedral (photo 22).

The lighter gray fine-grained rock contains approx mately 50 percent intermediate andesine (the crysta are somewhat better formed than those of the darke rock), 30 percent anhedral quartz, and 20 percen yellow- to deep-brown, pleochroic, irregular biotit Allanite is present in some of the specimens, as well a small amounts of apatite, magnetite, and zircon. Th average grain size is 0.3 mm and most of the constituent are anhedral. The composition is similar to that of biotite quartz diorite and this rock could represent dike-lik intrusions of plutonic material into the dark fine grained rock. The grain size is not typical of dikes o plutonic material elsewhere in the area.

Age Relations. It is definitely established that th gray fine-grained rock is younger than the dark fine grained rock (see photo 6). The medium-grained quart diorite as well as the granite is locally cut by dikes o both types of the fine-grained rock and quartz diorit xenoliths are included in masses of the fine-graine gray rock. The quartz diorite and the granite also occu as dikes in the dark, fine-grained rocks in other localities The gray fine-grained rock cuts both the granite an quartz diorite (see photo 5). Neither the granite no the quartz diorite cuts the gray, fine-grained rock.

Origin. Fine-grained rocks of the type described i this report have received little, if any, mention in othe works on the rocks of the Sierra Nevada. The lack o detailed work as well as the smaller scale mapping o older work probably accounts for the lack of discussio of the fine-grained rocks. Hamilton (1956) describe some fine-grained rocks of hybrid origin, from the Huntington Lake region, that are mineralogically and texturally similar to the fine-grained rocks of the As Mountain complex.

The fine-grained rocks are probably fine-grained intrusives, hybrid rocks (presumably altered in place fro metamorphic rocks), or mobilized hybrid rocks.

Texturally and mineralogically, both the Huntingto Lake and Ash Mountain fine-grained types could be igneous rocks. Poorly developed crystals are not uncommon in the plutons elsewhere in the area. The fact that the fine-grained rocks intrude granite and quartz diorite does not settle the question of whether they intruded as igneous rocks or were mobilized during alteration.

East of Ash Mountain Park Headquarters hornfelsic fine-grained rocks grade into schistose rocks. The hornfelsic schists resemble the fine-grained rocks of the Ash Mountain complex, but the writer wishes to emphasize that he found no transition between the two types and thus cannot be sure they have the same origin. One of the dark, fine-grained specimens from the Colony Mill road has foliation that may be inherited from a metamorphic source, but in the body mapped as Ash Mountain complex the fine-grained rocks are massive.

Along the Colony Mill road, the Ash Peaks truck trail (which extends northwest from the Park Headquarters to the North Fork of the Kaweah River), and near the area of outcrop of the Ash Mountain complex, much metamorphic material is exposed. The fine-grained rocks were found only in areas of metamorphic rocks.

It is suggested that the dark complex rocks were formed by the alteration of metamorphic rocks. The textural and mineralogical resemblance of the dark fine-grained rocks to some of the dark inclusions in the granitic rocks may mean the two types are genetically related.

MESOZOIC PLUTONIC ROCKS

Plutonic rocks underlie approximately 130 square miles of the mapped area, and occur as separate mappable bodies. Each mappable unit with the exception of the alaskite is designated by a local geographic name and a rock name or the term pluton.* Pluton is used in this report in much the same way that formation is used in sedimentary rocks. The plutons are mappable, relatively homogeneous units that can generally be designated by one of the standard rock names. Where the variation is greater than the limits of a standard rock name, the term pluton is used to save the use of a rather cumbersome compound name. The use of local geographic names for the plutons is intended merely as a convenient device for referring to mappable bodies. The Sequoia area is isolated from areas where detailed work has been done on Sierra Nevada plutonic rocks, and no attempt has been made to correlate the Sequoia rocks with those of other areas. It should be emphasized that the names employed in the Sequoia area are not proposed as permanent names.

The petrographic data are summarized to limit repetitious discussion under the pluton sub-heading. The mineral composition of the plutonic rocks is summarized in table 1. This compilation eliminates the necessity for detailed descriptions of the amounts and ranges of the various minerals for each pluton. In addition the mineralogic range and average composition of some of the larger masses (the Giant Forest and Big Meadow plutons, and the Weaver Lake quartz monzonite) are shown by 76 thin section modal analyses that were made using the point count method of Chayes (1949, pp. 1-11). The description of minerals will also be limited to unusual or particularly important features. The textures throughout the granitic suite are generally hypautomorphic granular, medium- to coarse-grained, with locally porphyritic and seriate facies. The texture in the gabbroic rocks, on the other hand, is extremely variable. In general the gabbro is xenomorphic granular, medium-grained; but locally it contains irregular poikilitic hornblende crystals as large as 6 inches across.

Throughout the plutonic suite, minor late- or post-magmatic alterations are common. The plagioclase is saussuritized to some extent in all the rocks with the resultant development of epidote, clinozoisite, and calcite. Both the potash feldspar and plagioclase show some sericitization. The zoning of some plagioclase crystals is accentuated by thin, cloudy layers of fine sericite or clay minerals, and some plagioclase cores are completely altered to a mass of unidentified clay minerals. Most of the hornblende is in part altered to penninite (chlorite) and less commonly epidote and calcite are developed as patches in the hornblende. Thin, irregular sphene stringers in the hornblende are probably also the result of secondary reactions. The green hornblende that surrounds the crystals of brown hornblende and pyroxene in the gabbro might also be considered an alteration. This is merely a matter of where the line is drawn between late-magmatic and post-magmatic reactions. Biotite has the same alterations as the hornblende, but penninite is more common. Some of the brown biotite is

Table 1. Summary of mineral compositions of the plutonic rocks.

Rock	Plagioclase		Potash feldspar	Quartz	Biotite	Hornblende	Others	No. of thin sections studied
	An	Percent						
Alaskite	10	20–30	40–50	30	0–tr.		Muscovite 0–tr.	3
Lodgepole granite	15–25	15–45	25–45	25–35	5	0–tr.		7
Pear Lake quartz monzonite	20–25	40	30	30	tr.		Muscovite tr.	1
Cactus Point granite	10–25	10–20	40–70	15–30	3–5	0–tr.	Muscovite 0–tr.	4
Big Baldy granite	20–30	5–60	15–55	20–35	3–5	tr.–2		5
Weaver Lake quartz monzonite	10–35	25–45	25–40	25–35	1–5	0–tr.		11
Big Meadow pluton	30–42	30–75	2–35	15–30	4–7	0–tr.		20
Giant Forest pluton	18–48	30–75	tr.–40	10–35	4–14	0–10	Pyroxene 0–tr.	70
Tokopah porphyritic granodiorite	30–40	45	22	23	5	5		1
Clover Creek granodiorite	20–45	40–55	15–30	20–25	4–7	4–7		3
Cow Creek granodiorite	30–40	50–65	10–15	15–30	5	tr.		2
Potwisha quartz diorite	30–55	55–70	0–tr.	15	7–10	8–20		2
Elk Creek gabbro	45–80	50–85		0–5	0–5	tr.–48	Pyroxene 0–20 Olivine tr.	7

Sphene, magnetite, zircon, apatite, allanite are common accessory minerals; monazite, garnet, and pyrite only locally present.

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* *Pluton* was first defined by Hans Cloos (1928) as an all-inclusive, noncommital term to apply to plutonic masses. Cloos in addition proposed numerous modifying terms to subdivide plutons on the basis of form, size, and other features. Most of this nomenclature has not been adopted, but the term pluton is coming into general use for bodies of igneous rock formed by slow cooling, particularly where the form of the body is irregular or unknown.

Table 2. Modes of granitic rocks.

No.	Plagioclase		K-feldspar	Quartz	Biotite	Hornblende	Counts[4]
	Percent	Kind					
Giant Forest pluton							
1[1]	61	Sodic and.[2]	9	15	12	3	480[3]
2	52	An45	4	26	10	8	470
3	45	An38	5	24	11	15	498
4	52	Olig-and.	16	22	7	3	467
5	44	An40	7	27	13	9	522
6	49	Sodic and.	4	30	11	6	542
7	66	Sodic and.	8	12	9	5	500
8	43	An45–32	13	32	9	3	492
9	49	Sodic and.	12	24	11	4	485
10	54	Sodic and.	7	20	12	7	419
11	46	Sodic and.	12	28	9	5	567
12	44	Int. and.	12	29	11	4	542
13	49	An34–30	6	24	14	7	552
14	46	An40	6	28	11	9	512
15A	44	An40	6	28	14	8	480
15B	53	An40	10	19	12	6	615
16	59	An39–32	5	14	17	6	520
17	46	Sodic and.	1	31	16	6	421
18	46	An43	6	23	13	12	494
19	53	Andesine	4	24	10	9	554
20	60	Sodic and.	1	21	17	1	593
21	60	An40	2	23	15	—	543
22	49	An50–36	9	23	10	9	438
23	39	Int. and.	26	18	12	5	501
24	50	Andesine	24	19	4	3	494
25	45	Int. and.	17	25	10	3	519
26	49	An40	13	22	9	7	522
27	52	An40–32	13	24	7	4	476
28	52	An35	13	16	14	5	414
29	35	An40–28	19	27	12	7	743
30	46	An40	3	26	17	8	471
31	50	An40	16	19	10	5	452
32	42	An37–32	20	29	7	2	537
33A	46	An44	17	23	10	4	527
33B	52	An44	6	28	9	5	573
34	50	An18	—	30	20	—	472
35	37	An40–27	27	27	5	4	425
36	47	An40	18	20	8	7	514
37A	31	An45	30	27	8	4	525
37B	37	An45	19	32	7	5	494
38	50	An38	10	24	9	7	484
39	34	An40–28	21	29	7	9	550
40	42	An48–27	12	30	12	4	552
Giant Forest pluton—Continued							
41	49	An35	11	26	10	4	498
42	47	An45	8	20	17	8	444
43	46	Int. and.	10	25	10	9	450
44	41	Andesine	20	29	8	2	614
45	55	An40-28	4	23	12	6	735
46	44	An39	12	25	11	8	595
47	48	An48–25	9	23	15	5	567
48	50	Sodic and.	9	24	9	8	588
49	57	An40	15	12	11	5	472
50	57	An40–35	8	17	12	6	542
Average	48	--------------	11	24	11	6	
Big Meadow pluton							
1[1]	41	An42–30[2]	20	29	10	tr.	605
2A	51	An36	19	26	4	—	589
2B	40	An36	23	32	5	—	497
3A	42	An32	16	32	10	—	540
3B	35	An32	22	40	3	—	564
4	51	An35–25	15	28	6	tr.	476
5	48	An33	9	25	14	4	427
6	35	An35	36	23	6	tr.	481
7	37	An32	30	26	7	—	491
8	34	An40	37	25	4	—	515
9	46	An33	14	28	11	1	525
10A	46	An30	21	22	9	2	587
10B	49	An30	17	25	8	1	489
Average	43	--------------	21	28	7	1	
Weaver Lake quartz monzonite							
1[1]	36	An35–25[2]	29	32	3	—	526
2A	41	An30	24	31	4	—	468
2B	39	An30	25	32	4	—	497
3	31	Sod. olig.	35	30	4	—	561
4A	34	An32	29	32	5	—	606
4B	41	An32	29	26	4	—	485
5	30	An30–10	29	34	7	—	443
6	35	An30	27	32	5	1	505
7	30	An35	29	32	6	3	398
8	37	An30	34	24	5	—	471
Average	35	--------------	29	31	5	< 1	

[1] Location of specimens shown on figure 2.

[2] Specimens showing range in anorthite content indicate zoning determined on universal stage, for other specimens the most calcic plagioclase is indicated.

[3] Number of regularly spaced mineral identificatons made after the manner described by Chayes (1949, pp. 1-11) from a standard thin section (¾ to 1 inch wide and about 1½ inches long).

[4] Duplicate analyses of selected thin sections resulted in variations of as much as 2 percent in the various constituents.

rimmed with a green mineral that has the properties of biotite. The green mineral is probably a transitional stage in chloritization. A minor amount of serpentinization is found along the curving fractures in the olivine of the gabbro.

Uniformity of both texture and mineral content is characteristic of many of the plutons, particularly the smaller ones; but the larger plutonic bodies show marked variations, particularly in mineral content. Some of the variations may be due to missed contacts, but variations were also noted within mappable units. Variation in mineral content in the three most widespread plutons is shown in figure 3. The method used to portray these data is that of Johannsen (1932). Each point on the diagram represents a modal analysis for which the quartz and feldspar have been recalculated to total 100 percent. The great advantage of the triangular diagram is that it permits the comparison of a great number of different specimens more rapidly and with more clarity than the table of modes (table 2). Another characteristic of these granitic rocks that can be shown by a triangular diagram is the hornblende-biotite ratio and the color index (percentage of dark minerals). Figure 3 also shows these features, using biotite, hornblende, and other minerals as the corners of a triangle. The combination of these two triangular plots permits a rapid comparison of the characteristics of several granitic masses. As a check on the homogeneity of hand specimens, two thin sections were cut at right angles from homogeneous, equigranular specimens that were considered representative of the major plutons. Figure 3 shows the variations in these specimens as determined by modal analyses. Variations of 10 percent or more in the major constituents of the same hand specimen suggest that whereas a large number of analyses permit statements on gross composition and range of composition, caution should be used in drawing conclusions based on the comparison of a few modes unless homogeneity of specimens has been established.

The Plutons

In the following discussion each pluton will be described separately with emphasis on features that distinguish the unit in the field. With regard to the 13 named

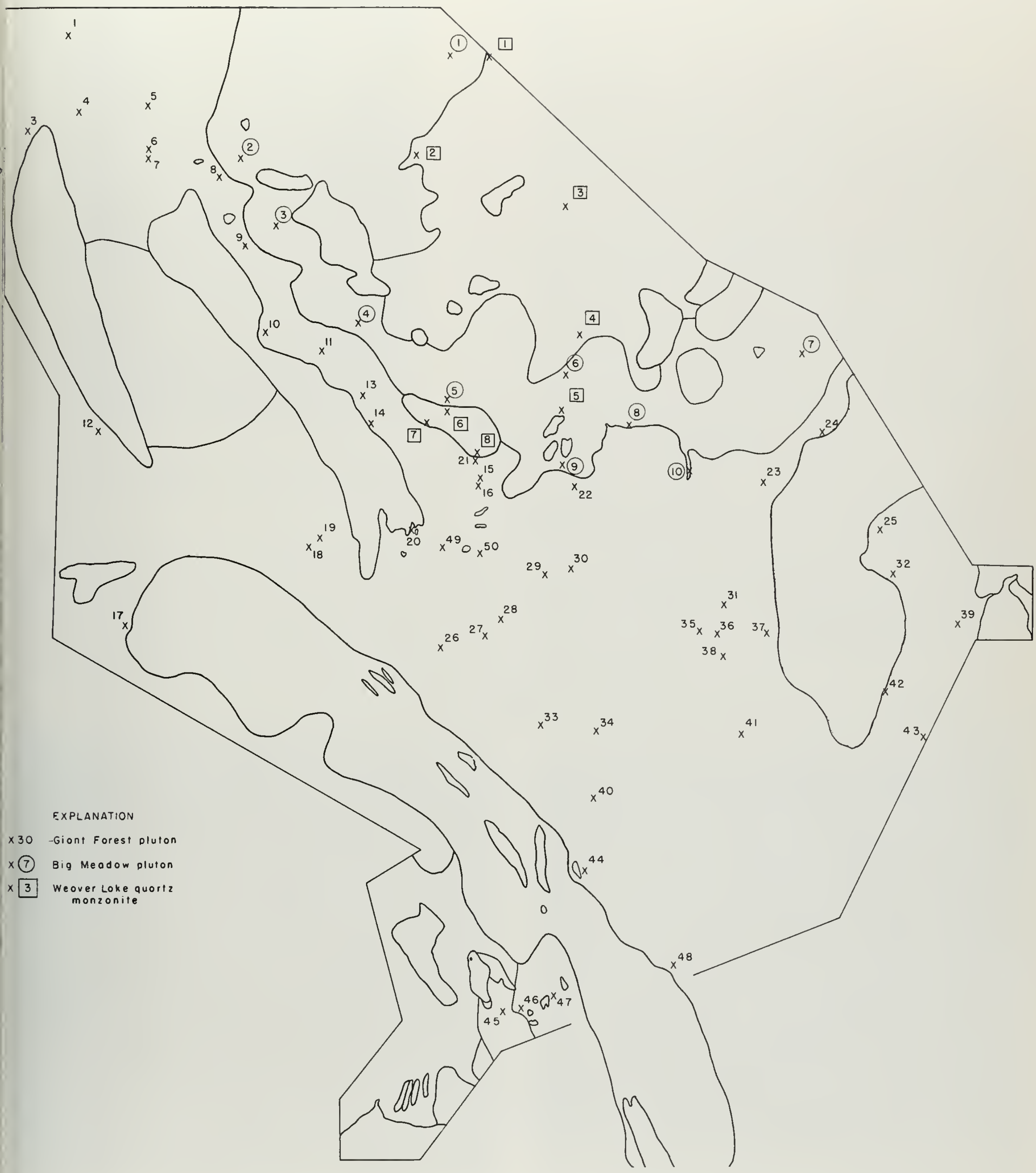
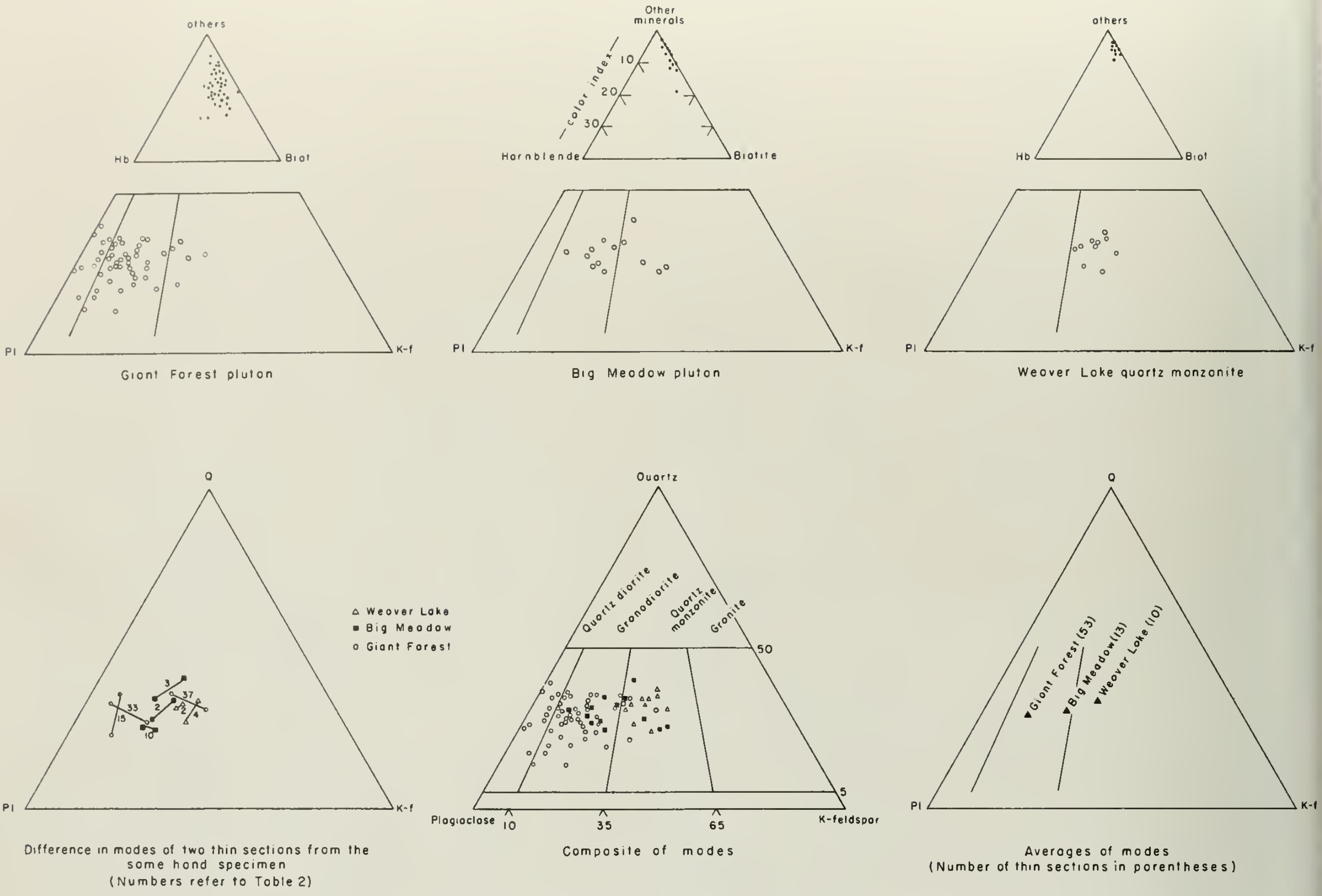


FIGURE 2. Location map of modally analyzed granitic rocks.



Giant Forest pluton

Big Meadow pluton

Weaver Lake quartz monzonite

Difference in modes of two thin sections from the same hand specimen (Numbers refer to Table 2)

Composite of modes

Averages of modes (Number of thin sections in parentheses)

MODAL DATA – GRANITIC ROCKS

FIGURE 3.

plutons, it must be considered that this reflects an attempt by the writer to delineate all units not positively correlative. In some instances, units that may be correlative (e.g., Lodgepole and Pear Lake masses, Clover Creek and Giant Forest masses) are shown as separate units in the belief that only with the mapping of a larger area can a positive correlation be established or disproved.

Aplite and pegmatite dikes are present in all of the plutons, but are not common. The aplite is a light-gray to white, fine-grained rock, with a sugary texture, consisting of quartz, potash feldspar, and sodic plagioclase, with local traces of biotite and hornblende. Pegmatite is much less common, but it is well distributed, and occurs as dikes, cores of aplite dikes, rims on aplite dikes, and bulbous knobs on aplite dikes, listed in the order of decreasing abundance. The pegmatite consists mostly of potash feldspar, quartz, and albite, and commonly shows graphic texture. Biotite and muscovite are less common, and pink garnet, epidote, and black tourmaline (schorlite) are only locally abundant. Tourmaline is particularly abundant northwest of the Ash Mountain Park Headquarters where it is invariably surrounded by or intergrown with quartz in vermicular and graphic

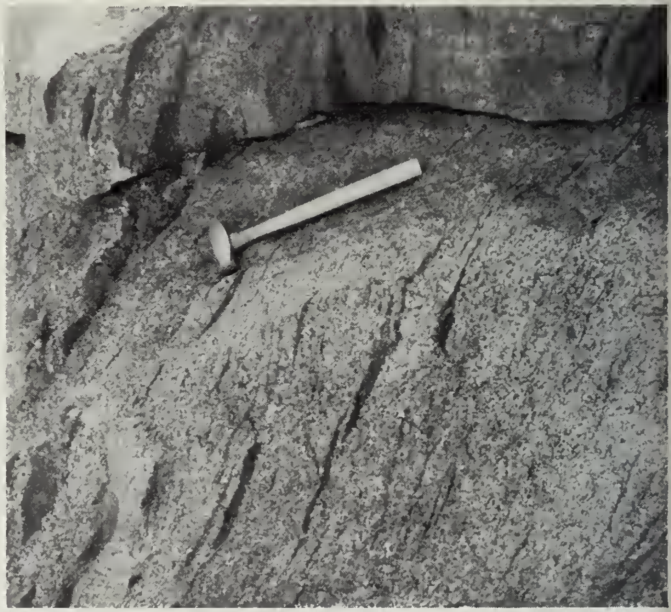


PHOTO 3. Well-developed foliation formed of drawn-out inclusions in the Giant Forest pluton near Bacon Meadow.

PHOTO 4. A dike of rock similar to the Giant Forest pluton cutting hornfels and schist west of Little Baldy. Darkening near the contact results from a concentration of hornblende that has formed by reconstitution of schist.

atches. The encroachment of these tourmaline-quartz nasses into feldspar-quartz intergrowths indicates tour-naline replacement of feldspar.

Elk Creek Gabbro. Four small masses of gabbro total-ng about a square mile in area, crop out along and near lk Creek, an intermittent stream northwest of the Ash ountain Park Headquarters. The gabbro is easily distin-uished by extreme dark color, prominent hornblende, narked variation in grain size, and a dull gray to red-lish-brown soil locally developed in areas of scattered utcrop.

Most specimens are about half calcic plagioclase and alf dark minerals, with hornblende predominant. Au-ite, hypersthene, and red-brown biotite unlike that of he other granitic rocks are present in lesser abundance; livine is rare. The most striking feature of the gabbro s the local development of poikilitic, brown hornblende rystals as large as 6 inches across (photo 20). Both the yroxene and brown hornblende commonly are rimmed y pale green hornblende.

Potwisha Quartz Diorite. The Potwisha quartz dio-ite underlies about a square mile in the vicinity of otwisha Camp. It has a distinctive dark-gray color, an bundance of dark inclusions and schlieren, and is read-ly distinguishable from the other units in the plutonic uite.

The quartz diorite is in gradational contact with the iant Forest pluton, but is mapped separately because t has a distinctive color and mineral content. The abun-lance of dark inclusions and schlieren, and the nearness f gabbro and metamorphic rocks suggest the Potwisha uartz diorite is a contaminated facies of the Giant For-st pluton.

Cow Creek Granodiorite. The Cow Creek granodiorite is named from exposures along Cow Creek along the west side of the area. The granodiorite is light gray, and finer grained than the rocks of the Giant Forest pluton. Little is known about this unit as it was studied only briefly along Cow Creek and Yucca Creek, owing to the dense brush in this part of the area.

The specimens from Cow Creek are leucocratic granodiorite with predominant sodic andesine and only 5 percent biotite. The specimens from Yucca Creek have a similar mineral content, but a more granulose texture. Hybridization from the adjacent schist, which has a pronounced embayment along Yucca Creek, is a possible cause for this atypical granitic texture.

Clover Creek Granodiorite. Three small masses, chiefly granodiorite, totaling about a square mile in areal extent, crop out near the West Fork of Clover Creek and south of Colony Meadow. These rocks are distinguished chiefly by a salt and pepper speckled appearance, resulting from imperfectly formed hornblende and sphene crystals sprinkled through the rock. The finer fabric of the Clover Creek rocks was used as the most significant factor in separating these rocks from the mineralogically similar Giant Forest rocks. Possibly the Clover Creek granodiorite masses are small stocks of the Giant Forest pluton, and consequently finer grained.

Tokopah Porphyritic Granodiorite. The Tokopah porphyritic granodiorite is named from exposures in upper Tokopah Valley in the eastern part of the area. The Tokopah pluton is probably the most distinctive rock in the area. It is notably porphyritic with stubby to equant, subhedral to euhedral, pink to gray microcline phenocrysts as large as 25 mm across, set in a medium-grained groundmass averaging 3 to 5 mm. Some of the plagioclase also is present as phenocrysts as large as 15 mm in length.

The microcline phenocrysts are probably late replacement crystals, despite the fact that the euhedral appearance suggests early formed crystals. The phenocrysts

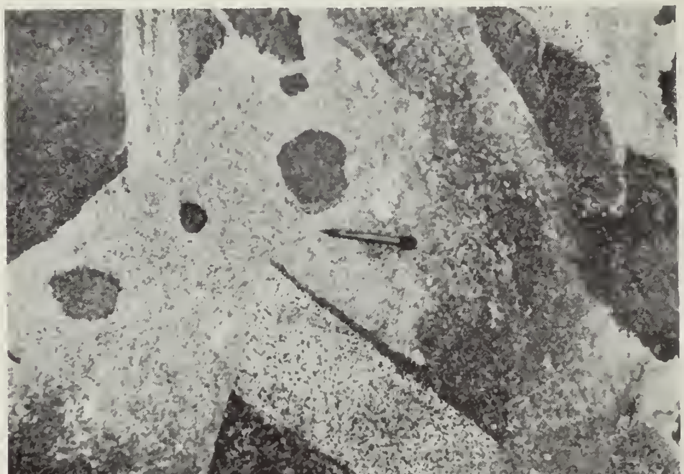


PHOTO 5. A typical exposure of rock of the Ash Mountain complex. Medium-grained quartz diorite cuts dark, fine-grained rock; gray, fine-grained rock cuts both.

PHOTO 6. An intrusion breccia of gray, fine-grained rock into dark, fine-grained rock of the Ash Mountain complex.

are commonly poikilitic, and include biotite and hornblende near the margin of the crystals. Some irregular poikilitic microcline masses, interpreted as replacement crystals, may be incipient phenocrysts.

Giant Forest Pluton. The Giant Forest pluton is named from somewhat weathered exposures in Giant Forest. The freshest outcrops of this unit are found in roadcuts along the Generals Highway west of the Lodgepole Campground. This pluton is by far the most exte sive in the area; it crops out over approximately square miles in a broad, irregular, northwest-trendin band.

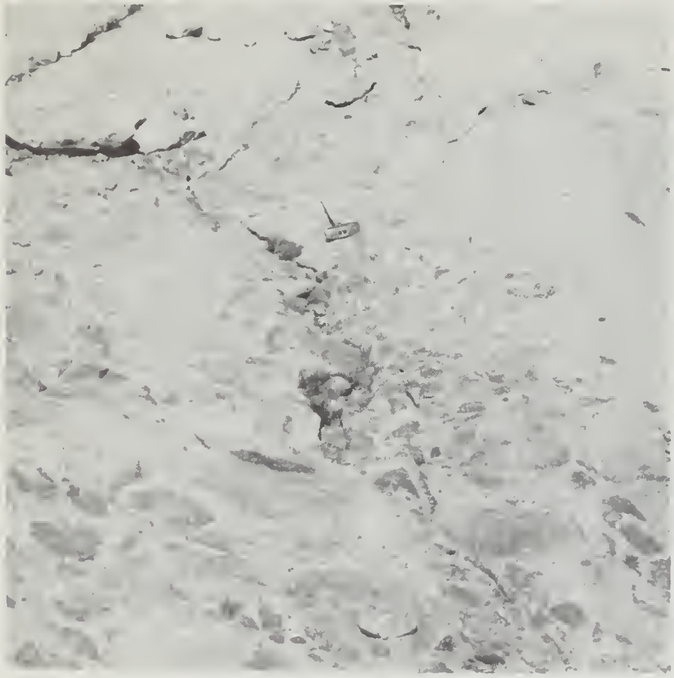


PHOTO 7. A swarm of inclusions in the Tokopah pluton.

The exposures are light gray to medium gray depen ing on the amount of dark minerals. About 5 to 10 pe cent each of the subhedral to euhedral hornblende an subhedral biotite is the most characteristic feature the rocks of this pluton. Biotite is generally more con mon, although the first impression from a typical hor blende-bearing specimen is that hornblende predom nates, probably because of the prominence of the wel formed hornblende crystals.

The Giant Forest pluton ranges from quartz diori to intermediate quartz monzonite, but is predominantl granodiorite (fig. 3). Hornblende is generally presen along with biotite, but locally only biotite is presen The most obvious variation from the typical hornblend bearing granodiorite is the biotite granodiorite alon the east margin of the largest roof pendant. Near th contact with the roof pendant, hornblende is absen and large irregular microcline phenocrysts have forme The variation may be due to reaction with the met morphic rocks, or it could be a separate intrusion. N contact was seen with the more typical hornblende-bea ing rocks, but a contact could be missed because acce is difficult and the cover is extensive.

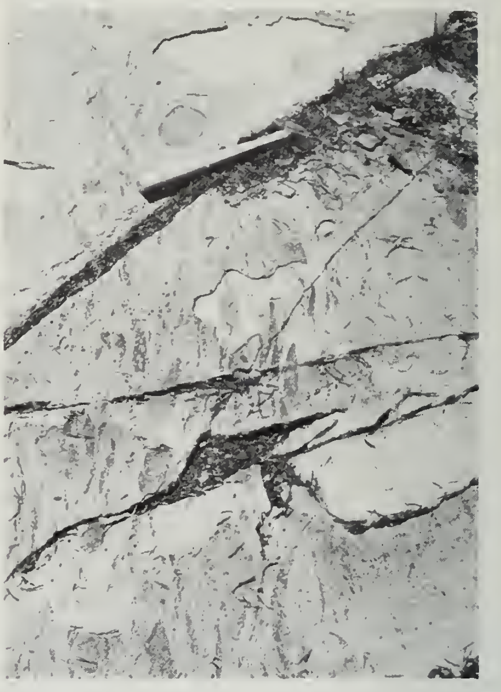


PHOTO 8. Foliation in the Tokopah pluton. Inclusions are elongated and bent around the originally less plastic bodies.

Coarse-grained biotite granite is found in the are mapped as Giant Forest pluton, south of Big Baldy an south of Switchback Peak. Further work would almos certainly disclose that the granite could be mapped a a separate pluton. The approximate area that contain the coarse-grained granite within the Giant Forest plu ton is shown on the geologic map (pl. 1) by the symb ''ggr.''

Photo 9. Injection zone at the contact of the Giant Forest pluton with schist east of Hospital Rock camp.

The most common mineralogic variation within the rocks that are a definite mappable unit is the variation in the amount of microcline. The microcline commonly shows evidence of having replaced earlier formed plagioclase (photo 18). The common supposition that quartz monzonite has more quartz, fewer dark minerals, and more sodic plagioclase than quartz diorite is not readily demonstrable in the specimens studied from the Giant Forest pluton. The sporadic occurrence of microcline seems to be the governing factor in the determination of the names of the specimens studied. No systematic distribution of the various rock types was found, but microcline was somewhat more abundant in the eastern part of the mapped area.

Big Meadow Pluton. The Big Meadow pluton is named from outcrops around Big Meadow, and it crops out over approximately 25 square miles in an arcuate band extending from north of Big Meadow south and east to Twin Lakes. The pluton is distinguished by its medium grain size (4 to 5 mm) and its low color index relative to the Giant Forest pluton (fig. 3). Fresh specimens are light gray, and some specimens have a pinkish cast. The Big Meadow rocks, however, are easily recognized as a unit. The grain size varies somewhat, but the light color and the generally similar texture throughout gives the rock a homogeneous appearance.

The Big Meadow pluton contains rocks ranging from granodiorite to quartz monzonite and the average of the 13 modes determined (fig. 3) is a granodiorite near the boundary of the quartz monzonite field.

The difference in rock names for individual specimens is probably in part the result of the sporadic occurrence of late microcline. The dark mineral content is fairly constant and the plagioclase has essentially the same anorthite content throughout the body.

Weaver Lake Quartz Monzonite. The Weaver Lake quartz monzonite is named from exposures around Weaver Lake in the northeast part of the area. The largest mass crops out over about 12 square miles. Seven much smaller masses, probably satellitic to the large mass, are exposed around the periphery of the main mass. Exposures are notably light gray and the distinguishing features are the fine grain size and the low color index. The texture is xenomorphic granular and the grains average 1 to 2 mm. Biotite is sprinkled sparsely through the rock; hornblende is rare.

Photo 10. Lit-par-lit injection of Giant Forest pluton material into schist with later pegmatite dike (beneath the hammer).

The Weaver Lake rocks are readily distinguishable from most of the other plutonic rocks, but are almost identical with some of the aplite. Some of the smaller masses may be aplite, but they do not generally have the distinctive sugary texture of the aplite dikes. The Weaver Lake quartz monzonite may have been the source for many of the satellitic dikes in the area.

Pear Lake Quartz Monzonite. The Pear Lake mass is well exposed around Pear Lake in the eastern part of the area. It is a light-colored, coarse-grained rock that contains prominent pink potash feldspar, as well as white calcic oligoclase, gray quartz, and a minor amount of biotite.

Certain resemblances are apparent between the Pear Lake quartz monzonite and the Lodgepole granite. Both are coarse grained and have essentially the same minerals in about the same proportions. The Pear Lake mass, however, contains pink potash feldspar instead of the pinkish gray to salmon colored potash feldspar in the Lodgepole pluton. Microcline is predominant in the Lodgepole granite and microcline microperthite predominantes in the Pear Lake mass. Also the plagioclase is slightly more calcic in the Pear Lake mass. These minor differences may, however, be variations within a single intrusive unit.

Lodgepole Granite. The Lodgepole granite is named from the prominent exposures near the Lodgepole Campground. The granite crops out over about 7 square miles in an elongate body extending from Little Lake to south of Panther Peak. In addition, two small masses intrude the Giant Forest pluton, north of Heather Lake.

PHOTO 11. Prominent joint system near Emerald Lake.

The distinguishing features of the granite are the coarse grain size, the seriate texture, and the distinct color difference of the two feldspars. The grain size ranges on the average from 5 to 10 mm but commonly grains as large as 15 mm and rarely as large as 25 mm are found. Locally gray quartz forms glomerophenocrysts as large as 25 mm across. The potash feldspar is pinkish gray to salmon colored and the sodic oligoclase is gray to white.

The contact with the Giant Forest pluton is generally sharp, but near the south end of the Lodgepole granite mass, scattered outcrops contain gradational types between the two varieties, suggesting that at least locally there is a mixed zone between them. This may be the result of mixing along the contact where local mushy spots were present in the Giant Forest pluton at the time of the Lodgepole granite intrusion.

Big Baldy Granite. The Big Baldy mass is named for Big Baldy, the highest point on a prominent ridge in the northwest part of the area. The granite is exposed over an area of about 4 square miles and is bounded on the east and west by metamorphic rocks. It is medium grained, contains small amounts of dark minerals, and is sparsely porphyritic with potash feldspar phenocrysts. It may be in part correlative with the Cactus Poin granite.

In most of the specimens, potash feldspar makes u about half of the rock, and oligoclase and quartz eac make up about a quarter of the rock; small amount of biotite and hornblende also are present. In one specimen the usual plagioclase potash feldspar ratio was reversed, but this may be the result of an unrepresentativ sample because of the small size of the thin section.

Cactus Point Granite. An area of about 5 squar miles around Cactus Point, a small knob northeast o the Ash Mountain Park Headquarters, is composed o granite that is commonly light gray on fresh exposures but fresh exposures are rare; the weathered rock commonly has a yellowish tint. A distinctive weathering feature of the granite is the iron-stain halo around biotit and magnetite, which gives the weathered rock a mottle appearance.

Two different types of granite appear to be presen within the mapped area. Near the Ash Mountain Park Headquarters, and west of the mapped area, the granit is medium-coarse-grained and contains red-brown biotit and scattered pink garnet crystals; northeast of th Headquarters, the granite is fine-medium-grained, and contains traces of hornblende. The two varieties may b separable, but brush cover precludes detailed study in this part of the area.

Alaskite. Five small alaskite bodies crop out in th northern part of the area, which in aggregate cove

PHOTO 12. Giant Forest plutonic rock invading hornfels and schist, yielding a vein-like pattern and many xenoliths.

bout 2 square miles. The alaskite, seen from a distance, ppears light gray to white on fresh surfaces; but on ose observation it is seen to be cream-colored. The even, edium-grained texture, and an almost complete lack dark minerals makes this a readily mappable unit. nall shiny grains of magnetite are particularly noticeble, probably because of the paucity of other dark conituents.

Photo 13. Layered concentrations of hornblende in the Giant Forest pluton near Pear Lake.

Order of Intrusions

Lack of exposure of the contact and ambiguous conct relations hinder the study of the relative ages of e plutonic bodies. In the case of a body that cuts only e unit (e.g. the Lodgepole pluton) an age relative ly to the body cut can be ascertained. For these reasons is impossible to set up a complete order of intrusion, t the following relations have been determined on the sis of dike relationships, inclusion of blocks of inuded rocks, and transected foliation (photo 14). The lutons are arranged in geologic order (youngest on p), and no relationship is inferred between any of the ve listed.

(1) Alaskite
    Weaver Lake quartz monzonite
    Big Meadow pluton
    Giant Forest pluton
(2) Cactus Point granite
    Elk Creek gabbro
(3) Lodgepole granite
    Giant Forest pluton
(4) Tokopah porphyritic granodiorite
    Giant Forest pluton
(5) Pear Lake granite
    Giant Forest pluton

List (1) is an example of the increase of silicity with ecreasing age. The oldest rock is chiefly a granodiorite; is intruded by a granodiorite-quartz monzonite, which in turn intruded by a quartz monzonite; the latest trusive is an alaskite. The average modes of these asses also indicate this progressive increase in silicity fig. 3). These four units make an interesting pattern; e Big Meadow pluton intruded the Giant Forest luton, then the central area of the Big Meadow pluton as intruded by the Weaver Lake quartz monzonite, nd finally the small alaskite bodies, with one exception, were intruded within or around the edge of the Weaver Lake quartz monzonite. The significance of this pattern cannot be evaluated without further mapping to the northeast, but it is possible that the succeedingly younger units came up through the central, and possibly less solidified parts of the next older unit.

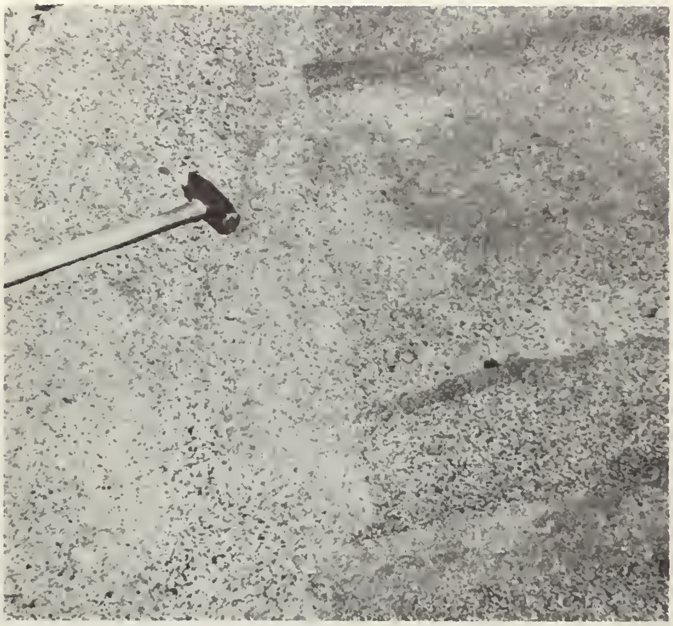


Photo 14. Contact of the Tokopah granodiorite (on left) with the Giant Forest pluton.

Age of the Plutonic Rocks

The plutonic rocks definitely post-date the metamorphic rocks, because the plutonic rocks truncate the beds in the metamorphic rocks and produce contact metamorphism of the pendant rocks. The age of the metamorphic rocks is not known, so age determinations from related plutonic areas must be taken as the only suggestion of the age of the Sequoia plutonic rocks.

In the Klamath Mountains, according to Hinds (1934), plutonic rocks similar in appearance to those in the Sierra Nevada cut Upper Jurassic beds. Sediments with Lower Cretaceous fossils and boulders of Sierra Nevada type plutonic rocks overlie a plutonic body.

In Baja California, Woodford and Harriss (1938) found Lower Cretaceous and early Upper Cretaceous fossiliferous metamorphic rocks intruded by granodiorite or quartz diorite that are comparable to the plutonic rocks of the Sierra Nevada. The plutonic rocks are probably Upper Cretaceous.

Larsen (1948) found that the southern California batholith intruded a thick series of volcanic rocks that was deposited on Triassic sediments. An erosion surface on the plutonic rocks is overlain by Upper Cretaceous rocks. The southern California rocks appear to be connected with those of Baja California and are similar in appearance to the southern California plutonic rocks described by Larsen.

Recent work on the absolute age of granitic rocks based on the lead-alpha activity ratio of the accessory minerals, particularly zircon, by Larsen and others (1952) has given an average age of 100 million years

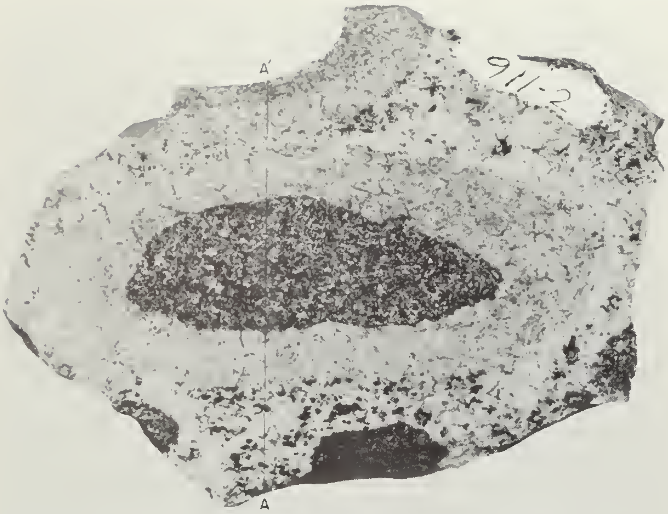


PHOTO 15. Orbicular inclusion measuring 8 inches in largest diameter.

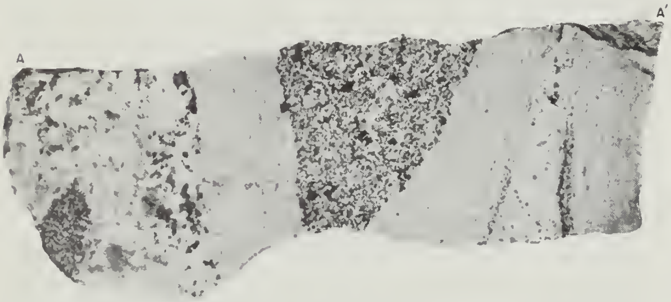


PHOTO 16. Sectional cut taken along line A-A' of Photo 15. Faint concentric structure is shown by trains of biotite. Pegmatite is found between the two rims on the right and surrounding the small inclusion on the left. A-A' = 5 inches.

(mid-Cretaceous) (Larsen, et al., 1954) for several granitic rocks from the Sierra Nevada. Five of these specimens were from the Bishop district, about 40 miles northeast of the Sequoia area (P. C. Bateman, oral communication). Determinations of radioactive argon show that the granitic rocks of the Yosemite Valley area are about 83 to 95 million years old (Evernden, Curtis, and Lipson, 1957).

The granitic province from the Klamath Mountains to Baja California contains intrusions as old as Upper Jurassic and as young as Upper Cretaceous. The granitic rocks of the Sequoia area belong somewhere within this range; recent work suggests a Cretaceous age.

Inclusions

Inclusions in plutonic rocks are of two kinds: (1) xenoliths, or fragments of material foreign to the rock that encloses them; and (2) autoliths, or fragments that represent an earlier crystallized part of the rock that encloses them.

Recognizable xenoliths of metamorphic material and plutonic material are locally present in the Sequoia area, and the layered hornblende concentrations are probably autolithic; but the great bulk of the inclusions are not easily identified with either type of inclusion. The inclusions of doubtful origin are dark, fine-grained, and co tain the same minerals as the plutonic rocks. The sar type of inclusion is common throughout the Sierra N vada, as well as in other plutonic complexes througho the world. Some of the inclusions of doubtful origin ca be shown to be xenoliths. None were conclusively show to be autoliths.

Layered Hornblende Concentrations. Regular ar irregular layers that are chiefly the result of hornblen concentrations are illustrated in photo 13. The layerin locally common, is particularly well developed in t Giant Forest pluton in the vicinity of Pear Lake, ar is weakly developed locally in the Weaver Lake ar Lodgepole masses. The layers in the Giant Forest pluto are autolithic, as they seem to be the result of the segr gation of early formed hornblende.

Rhythmic layering has often been described in th literature. Gilbert (1906) has described similar layerin in the Sierra Nevada and shows an illustration of the layering from a locality near the east boundary of the are of this report. Gilbert's illustration looks similar to phot 13. He mentions unconformities between the layers bu does not describe them. Such an unconformity is show in photo 13 where a dark layer is cut off by a wide light layer. Gilbert postulates the hornblende has settle and the layers are essentially the result of sedimentatio

Wager and Deer (1939) have described in great deta mineralogic layering in the Skaegaard intrusion i Greenland. They postulate the layering is due to the combination of settling and convection currents.

Bateman (1947) found ''angular unconformities'' an ''cross-bedding'' in banded gabbros in the east Sierr Nevada. The structures are shown by alternating felsi and mafic layers. The origin of these structures is postulated to be a combination of crystal settling and convection currents.

Hamilton (1951) has found, in the Huntington Lak area of the Sierra Nevada, ''long wispy bands rich i dark minerals, especially hornblende''; some of the band are considered to be hybrid in origin. One example indicates the hornblende concentrations are concentric layer around a hybrid rock. Hamilton considers that the hornblende crystals were formed from the associated hybri and metamorphic rocks.

Hornblende was observed to have formed from th interaction of igneous and metamorphic rocks at on locality near the south end of the eastern pendant in th Sequoia area. Near the contact, hornblende crystals hav formed from schist and have been freed into the granodiorite (see photo 4). Specimens show the hornblend has grown in the schist and has incorporated some o the groundmass material. Mechanical disintegration nea the contact may have freed the crystals, or the hornblende crystals may be residuals of schist assimilation Weight is added to the argument for the metamorphi origin of these particular hornblende crystals by the fac that the granodiorite in the area around the contact i practically devoid of hornblende. The layered hornblend concentrations, however, are not found near metamorphic or hybrid rocks, but metamorphic or hybrid rock could have been present at a higher level which has sinc been eroded away. The layering probably represents th settling of hornblende, and the recurring layers are th result of alternate settling and sweeping by convectio rrents. The alternation of quiet conditions to permit ttling, and moving magma to give mixing, would lead the rhythmic layering present in these rocks.

Dark Inclusions. The dark inclusions show marked riations in mineralogy, grain size, size, and shape. hey range from less than one inch to a few feet in diam- er. Normally they are subspherical to ellipsoidal, but ss commonly they have irregular outlines. The inclu- ons generally occur singly, but swarms are locally pres- t (see photo 7). The inclusions are much elongated here the foliation is well developed (photo 3). The ongation indicates a certain amount of plasticity or iidity and the variation in plasticity is well shown in ioto 8, in which elongated inclusions are bent around a unded inclusion that apparently was less easily de- rmed.

Plagioclase makes up slightly more than half of the ark inclusions and ranges from intermediate andesine calcic oligoclase. Scattered plagioclase phenocrysts as rge as 5 mm in diameter are common in the dark inclu- ons of the Giant Forest pluton. Some plagioclase phe- ocrysts are speckled with hornblende and biotite and ave an irregular outline that suggests the plagioclase ystals have grown late by replacement. Other plagio- ase phenocrysts are clear, well shaped, and were prob- bly freed mechanically from the surrounding plutonic ock. This process has been arrested in some specimens.

Microcline and quartz are present in subordinate mounts. Dark brown biotite comprises from 5 to 20 ercent of the dark inclusions. Common green hornblende mprises as much as half of some specimens. It is com- only sieve-like, and has apparently grown at the ex- ense of the surrounding minerals.

One specimen contains irregular remnants of mono- inic pyroxene included in hornblende. Two specimens om the Big Meadow pluton show a feature that closely esembles schiller structure in the hornblende. The hiller-like structure suggests that the hornblende may n part be the result of the replacement of pyroxene.

Well-formed needle-like crystals of apatite are con- entrated in the inclusions of nearly all the specimens. he maximum is 4 percent (photo 19), but many of the pecimens contain more than 1 percent of apatite. Much ore apatite is found in the inclusions than in the lutonic rocks. Zircon, magnetite, and sphene are pres- nt in nearly all the inclusions, sphene being slightly ore abundant than in the accompanying plutonic ocks.

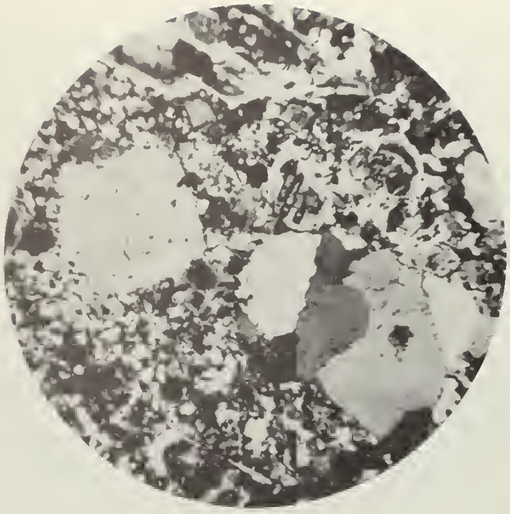
The texture of the Sierra Nevada dark inclusions has een variously described as "allotriomorphic" by Knopf nd Thelen (1906), "hypidiomorphic" by Pabst (1928), urlbut (1935), and MacDonald (1941), "suggestive of hornfels" by Grout (1937), and "crystalloblastic" by amilton (1951). In the area of this report, the in- usions are composed almost exclusively of anhedral ystals. The sieve-like nature of many of the larger ystals in the dark inclusions, as contrasted with the ell-formed subhedral plagioclase and hornblende crys- ls of the plutonics, suggests a replacement origin.

A correlation is noticeable between the individual lutons and the characteristics and amount of inclusions hey contain. The texture, mineralogy, and size of in- lusions depend to some extent on the nature of the enclosing rock, as is shown by the following generalizations. In the Giant Forest pluton, inclusions are generally abundant, of all sizes up to a few feet across, 0.2 to 0.3 mm in grain size, and porphyritic. In the Big Meadow pluton, inclusions are less common, generally small (normally less than 8 inches in diameter, but rarely as large as 2 feet), 0.1 to 0.2 mm in grain size, and commonly nonporphyritic. In the Weaver Lake pluton, inclusions are uncommon, small, 0.1 mm in grain size, and equigranular. Inclusions were not found in the alaskite plutons, and they are normally rare in the other plutonic units, except for the Tokopah granodiorite, which contains many inclusions. The plagioclase of the inclusions in the Giant Forest pluton averages intermediate andesine, and is generally in equilibrium with the plagioclase of the pluton. The plagioclase of the inclusions of the Big Meadow and Weaver Lake plutons is generally sodic andesine. Hornblende is common in the Giant Forest and Big Meadow plutonic inclusions and generally absent in the inclusions in the Weaver Lake pluton.

The variation in type of plagioclase and amount of hornblende indicates that the more felsic rocks have the more sodic inclusions. This is to be expected, as the inclusions would tend to reach equilibrium with the enclosing rock. The variation in abundance and size of inclusions is directly related to the order of intrusion and suggests that the early Giant Forest pluton may have had access to more material that was re-made into inclusions than did subsequent intrusions. The Giant Forest pluton is in contact with metamorphic rocks for many miles, but the metamorphic rocks are not in contact with the Big Meadow, Weaver Lake, and alaskite plutons. As the present surface is only a chance section across the area, the difference in contacts may not be significant; but the fact remains that the other plutons mentioned intrude the Giant Forest pluton and may have had less opportunity to receive xenolithic material.

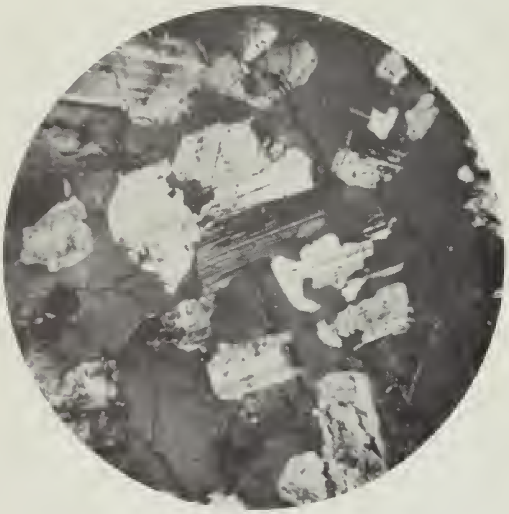
The alteration of added material is also controlled to some extent by the chemical composition of the material with which it is mixed. Xenolithic material that is close to the composition of the enclosing rock will probably be preserved, but the greater the chemical gradient, the more the chance of reaction. The abundance of hornblende in many of the dark inclusions, especially in the Giant Forest pluton, suggests a mafic parentage. Mafic material, presumably rich in hornblende and possibly pyroxene, if added to the Weaver Lake or alaskite plutons which are poor in dark minerals, would be subject to considerable reaction. The reactions and resultant recrystallization could also lead to the physical disintegration of the inclusion. Thus if equilibrium conditions were reached, inclusions would be rare. The rarity and small size of inclusions in the Weaver Lake pluton suggest that chemical gradient is important. Probably the decrease in numbers, size, and dark mineral content of the inclusions in the more acid plutonics is due to a combination of less access to material and the greater chemical gradient between the incoming granitic material and the added basic material of the inclusions.

The theories of origin of the dark inclusions are divided between those of autolithic origin and those of xenolithic origin. The following list gives the most common ideas on the origin of the inclusions.



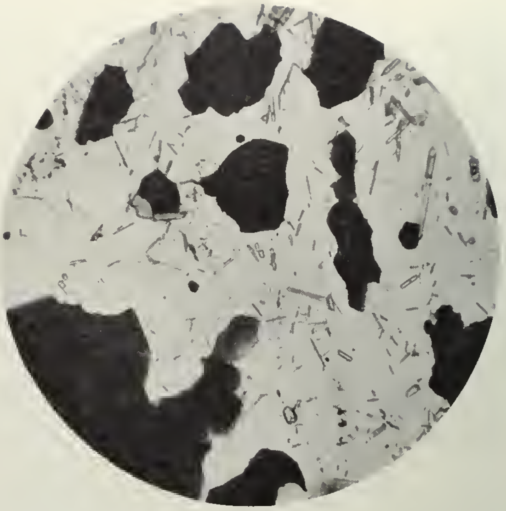
(X 20)

PHOTO 17. Recrystalized beta-quartz phenocryst (upper left) in a meta-volcanic rock north of Amphitheater Point (crossed nicols).



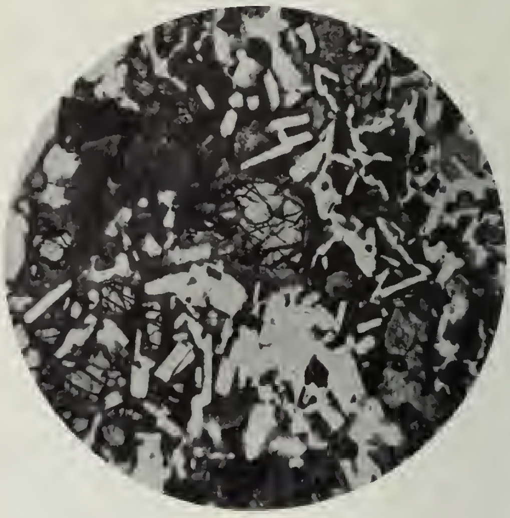
(X 15)

PHOTO 18. Plagioclase replaced by microcline in granodiorite of the Giant Forest pluton. In the lower right center corroded plagioclase fragments are in optical continuity indicating a former large crystal (crossed nicols).



(X 50)

PHOTO 19. Abundant apatite crystals in an inclusion from the Big Meadow pluton. Black crystals are biotite and the light background is plagioclase and quartz (ordinary light).

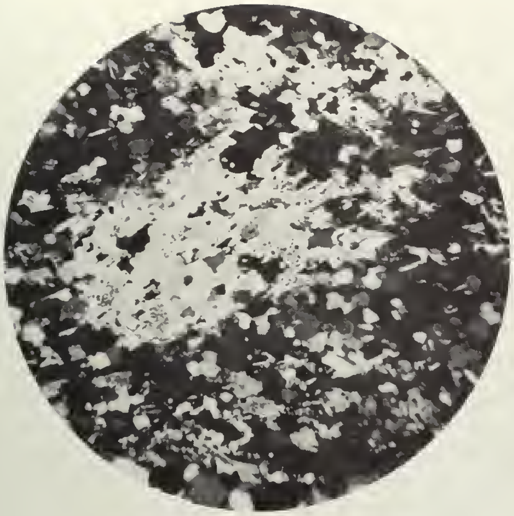


(X 30)

PHOTO 20. Large, poikilitic brown hornblende crystal (dark gray) in the Elk Creek gabbro including scattered residual crystals of olivine (strong relief) and hypersthene (pale gray). The white, lath-shaped crystals are bytownite and the black patches are magnetite (ordinary light).

1. Autolithic origin
    a. Magmatic segregation
    b. Stoping of a basic border phase
2. Xenolithic origin
    a. Recrystallization of older gabbro
    b. Recrystallization of metamorphic rocks

Magmatic segregation involves the settling of early formed crystals, or accretion around early crystallizing centers, to form nodular aggregates. Early formed hornblende crystals have concentrated near Pear Lake, but nothing resembling the dark inclusions has formed (see photo 13). The hornblende of the inclusions is not as well-formed as the hornblende in the layered concentrations, but is commonly sieve-like and appears t have grown late in the inclusion mass. The sieve-lik crystals are the ones that are noticed as phenocryst although most of the hornblende is in smaller anhedr crystals which are much smaller than the crystals the enclosing rock. If segregation is to account for th inclusions the early formed hornblende should resembl the well-formed crystals of the Giant Forest pluto Also, segregated inclusions would be subject to the sam subsequent reactions as the enclosing magma. Althoug many of the inclusions are in equilibrium with the e closing rock, there are such exceptions as inclusions wit

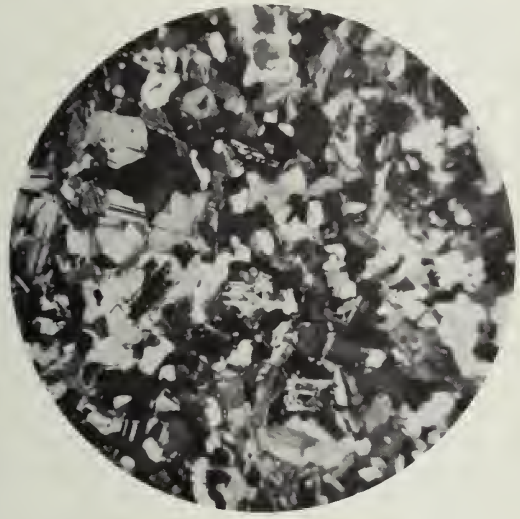


(X 20)

Photo 21. Large poikiloblastic muscovite crystal cutting the schistosity at an angle of 35°; specimen from a large xenolith east of Potwisha Camp (crossed nicols).

(X 25)

Photo 23. A broken plagioclase phenocryst in meta-quartz diorite porphyry north of Big Baldy. Note the prominent zoning as well as the fine mosaic groundmass inset with phenocrysts and fragments of plagioclase, hypersthene quartz and hornblende (crossed nicols).



(X 20)

Photo 22. Fine-grained, dark-gray rock of the Ash Mountain complex showing the xenomorphic granular texture (crossed nicols).

(X 25)

Photo 24. Embayed quartz phenocryst in meta-quartz diorite porphyry north of Big Baldy (crossed nicols).

ornblende and sodic andesine in the Weaver Lake plu- on, and abundant hornblende in inclusions in the Big Ieadow pluton. This suggests the inclusions were com- osed of material more basic than the magma, and in ome cases did not reach equilibrium.

Stoping of a basic border phase requires that an arly formed border phase be stoped by a later intrusive o form inclusions. A paper by Pabst (1928), which ncludes many petrographic descriptions, as well as hotographs and drawings of textures, is the only de- etailed description of Sierra Nevada inclusions. Pabst avors the idea of an early border phase that was first suggested for the Sierra Nevada inclusions by Gilbert (1906). Pabst covered a large portion of the Sierra Nevada in his study, and found that basic border facies are extremely rare and where they do occur, they contain inclusions themselves. Also the border facies present do not resemble the inclusions. Pabst says "the writer has not seen, in the Sierra Nevada, any rocks of the type of the autoliths described in any other form than as inclusions in granitic rocks."

In the Sequoia area no rock was found that would qualify as a basic border phase. The Potwisha quartz diorite is a more basic gradation of the Giant Forest pluton and has yielded some hand specimens that closely resemble inclusion material. Close observation of exposures, however, reveals abundant inclusions in the Potwisha pluton. To use the Potwisha quartz diorite as a basic border would present Pabst's problem; namely the presence of inclusions in the border phase necessitate another, more basic, border phase to account for these inclusions.

In the southern California batholith, inclusions are found that seem to be identical with those of the Sierra Nevada, judging by descriptions and illustrations. Hurlbut (1935) considers the dark inclusions of the southern California batholith to be the result of the reaction of the magma on included fragments of gabbro and applies the term "reaction inclusion" to the recrystallized fragments. His best evidence is the presence, in the inclusions, of hypersthene, augite, and bytownite-anorthite cores in plagioclase crystals. These minerals are common in the gabbros and are unknown in the enclosing rocks of the southern California batholith. The mineralogical evidence is supported by abundant field evidence showing mixed contacts of gabbro with quartz diorite and partially altered gabbro blocks.

Unfortunately, in the Sequoia area, there is little conclusive proof for or against this type of origin. The older gabbros are not in contact with plutonic units that contain abundant inclusions, except for a poorly exposed area close to the Potwisha Campground. The Cactus Point granite that is in contact with the Elk Creek gabbro has only scattered inclusions. The belt of outcrop of these two bodies is in an area that is thickly covered with brush, so the contact between the two formations was studied at only one locality. A foliated zone 30 to 50 feet wide between the gabbro and the granite represents a mixing and reaction of the two types. The zone is in part lit-par-lit and contains some dark inclusions. The presence of streaks and drawn-out inclusions strongly suggests some inclusions have developed from the reaction between the granite and the gabbro.

Many references are found in the literature concerning the incorporation and reconstitution of metamorphic rocks to form inclusions in plutonic rocks. In the Sequoia area incorporated metamorphic material has formed some of the inclusions. Photo 12 shows Giant Forest material that contains intimately veined schist and hornfels, which has released abundant xenolithic material into the magma. The xenolithic material is granoblastic and contains plagioclase, quartz, biotite, and hornblende. The texture and mineralogy are similar to those of the dark inclusions. Only the incorporation of some phenocrysts or the growth of sieve-like crystals is needed for the xenolithic material to be identical with the inclusions.

North of Crystal Cave a rounded fragment of foliated andesine amphibolite is present in a swarm of dark inclusions. A known xenolith in a swarm of inclusions suggests that the whole swarm is xenolithic, and that some of the other inclusions were altered so that no relic structure is now present. The amphibolite fragment would probably be stable in this environment where amphibole is abundant in the granitic rock.

The marked concentration of apatite in many of the inclusions, especially those of the Big Meadow and Weaver Lake plutons has also been observed by Knop and Thelen (1906) in the Mineral King district. They attribute the concentration to magmatic segregation Nockolds (1933) mentions many localities where concentrations of apatite are present in xenoliths that wer mostly derived from mafic igneous rocks. Nockolds considers the apatite to represent volatiles that become fixed in the inclusion during reciprocal reaction between the xenolith and the magma. The reciprocal reactions do not occur if the same minerals are present in both th inclusion and in the magma, even though there is difference in percentage. The schist and hornfels tha have been added to the Giant Forest pluton are in mineralogical equilibrium with the magma; but if such material were added to the Weaver Lake pluton, reciprocal reactions would take place to form an inclusion approaching mineralogic equilibrium with the Weaver Lake pluton. Also, gabbroic material added to any o the plutons would require a readjustment, and more so, in the more felsic masses. Apatite is more concentrated in the more felsic rocks; this may reflect the more extensive reciprocal reactions, as suggested by Nockolds.

Hurlbut (1935) lists apatite as occurring only as occasional grains in the southern California batholith The lack of apatite concentration seems to be a contradiction of Nockolds' theory, but the inclusion-bearing rocks described by Hurlbut are quartz diorites, and may not have the high apatite concentration characteristi of the inclusions in the more felsic bodies of the Sequoia area.

The Potwisha quartz diorite has abundant streaked out inclusions and a general dark color caused by an abundance of hornblende and biotite. The nearness o xenolithic metamorphic fragments, especially the abundance of marble, suggests the differential assimilation o schist similar to that observed near the Ash Mountain Park Headquarters. The Potwisha quartz diorite may b a belt contaminated by assimilated material, darker because of the mechanical disintegration of inclusions, a well as chemical reactions. The abundant drawn ou schlieren inclusions in the Potwisha body also sugges that the inclusions were more fluid and more capable of being mixed with the plutonic material.

Most of the dark inclusions are essentially in equilibrium with the enclosing magma. This is especially true in the Giant Forest pluton. The constituents are almost invariably anhedral and the inclusions contain "phenocrysts" that have grown late or have been mechanically freed from the enclosing rock. In the preceding discussion on modes of origin some facts favor a metamorphic origin for some of the inclusions.

The conclusion from the present study agrees with the statement by Grout (1937): that in the absence o some unusual chemical composition or some relict structure, it is frequently impossible to determine the origin of inclusions.

Orbicular Inclusions. About half a mile southeas of Twin Lakes an elliptical inclusion swarm approximately 50 feet by 10 feet in plan is exposed. Most of th inclusions in the swarm have gray coatings, but som have no coatings at all. The inclusions are the typica dark hornblende-bearing inclusions and the matrix i iotite granodiorite. Small patches of pegmatite are ound in this swarm, especially near the gray rims. The xposure near Twin Lakes was the only orbicular strucure observed in the area. Elsewhere inclusions are in harp contact with the enclosing material.

The cores of the orbicular inclusions are similar to ne previously described dark inclusions—predominantly ntermediate andesine with a small amount of quartz. ne-third of the specimen is composed of biotite and ornblende, hornblende being the most abundant. The atrix is a common biotite granodiorite composed of ntermediate andesine, microcline, quartz, biotite, and a race of hornblende.

The rims look sugary and fine-grained in the hand pecimen and are a maximum of one inch thick. Most f the rim, however, is made up of poikilitic microcline rystals as large as 3 mm across, in which are set abunant rounded quartz grains. A minor amount of biotite s present, which forms faint concentric streaks. Irreguar, corroded andesine crystals are also present in the ims.

The microcline crystals of the rim are elongated perendicular to the contact with the core. The ratio of longation is about 2 to 1. Some elongated quartz grains lso show this radiating trend. The weak radiating trend s not apparent in the hand specimen.

The contact of the rim with the core is sharp, but rregular; contact of the rim with the matrix is sharp n part, and elsewhere grades to a medium-grained pegatitic rock which is associated with the orbicular swarm s pockety masses or as an irregular zone around the rim.

A single group of orbicules in an area of 150 square iles suggests a rather unusual set of conditions. This s especially true when the abundance of dark inclusions the core rocks of the swarm) is considered. Another nomaly is the texture of the rim material. Though megacopically aplitic, the microcline is in large masses simiar to the late microcline in the other plutonic rocks. The mall patchy spots of pegmatite in the orbicular incluion swarm are also different from other pegmatite in he area.

The rims with the concentric and radiating structure esemble orbicules as described by Sederholm (1928), ohannsen (1932), and Eskola (1938). The orbicular ocks near Twin Lakes are not as complex as those of ther described localities, but they have all the general eatures, such as a nucleus, concentric and radiating tructure, an ellipsoidal shape, and an occurrence as a roup of similar bodies.

The three most probable theories of origin for rims f the Twin Lakes orbicules are: (1) a reaction between he core and the plutonic matrix; (2) some sort of sucessive crystallization of shells around the dark inclusion ucleus (either the rims crystallized before the matrix, r grew within an already solid or mushy matrix); and 3) selective replacement along inclusion contacts by a ate, active aplitic mass.

The relatively homogenous rim could be construed as reaction rim between the plutonic matrix and the dark nclusion core. The problem with such a theory is the eaction of a biotite-hornblende quartz diorite with a bioite granodiorite to produce a rock of granite composiion. The reaction seems impossible from a chemical standpoint. Another difficulty of a reaction origin is the volume of rim material. One of the larger orbicules has a core with a volume of 14 cubic inches and a rim with a volume of 50 cubic inches. This amount of material could not develop from a core-matrix reaction, especially when the core shows no evidence of any difference from other dark inclusions of the area.

The growing of the rim by successive crystallization of concentric layers is implied by the combination of concentric and radiating structures. Similar structures are common in orbicules of other localities and also are well known in oolites, which are thought to grow layer by layer.

The major problem in the origin of the Twin Lake orbicules is the concentration of rim material and the restriction of the rims to one locality. The abundance of small patches of pegmatite and the very acidic composition of the rims, as well as a microcline habit similar to that of the late replacing microcline of the plutonic units suggest a relation of the inclusion swarm to a pocket of late aplitic and pegmatitic material. Possibly the inclusion swarm, in a mushy matrix of plutonic material, was invaded by a mass of late pegmatitic and aplitic material. The dark inclusions would serve as suitable nuclei for the silicic material of the rims. Aplite dikes are found in the area with pegmatite cores, suggesting that pegmatite crystallized last from a silicic dike. The appearance of pegmatitic material as coatings on some of the rims and also as small patches between orbicules could be explained by the later pegmatite.

The crystallizing aplite material probably in part replaced existing plutonic material. There is ample evidence elsewhere in the area of late microcline replacing earlier plutonic material. The presence of corroded, irregular plagioclase in the rims, which is identical with that of the plutonic matrix, suggests that the rims grew late, or at least filled in and partly replaced a mushy matrix. Scattered intermediate andesine in a rim composed of 65 percent microcline and 25 percent quartz strongly suggests that the andesine is a replacement residual.

The fact that no tails or stringing out of rim material is found indicates that the rims had crystallized to an extent that any later movement of the swarm moved the coated inclusions and the interstitial pegmatite as a mass. Some post-rim-formation movement may be postulated from the fact that some biotite bands in the rims are transected at a low angle by the matrix material. This implies some erosion, which may be considered analogous to the wearing off of a pebble in a stream.

Some of the dark inclusions in the swarm are apparently uncoated. The contact with the matrix of one of the barren inclusions shows a thin rim of sugary quartz and small poikilitic microcline crystals. The writer checked all the thin sections of rock from the area that showed a contact between dark inclusions and plutonic material, and in no section was there a rim of fine, granular material—merely a sharp change in grain size. A patchiness of the aplite-pegmatite in the swarm could account for some inclusions being uncoated, or a difference in the degree of crystallization around the inclusions might make some easier to coat.

The aplitic-pegmatitic material could have been intruded after the matrix and inclusion swarm were essentially solid and the contacts of matrix and inclusions might form suitable zones for replacement. The marked chemical gradient between the two types would tend to promote a chemical reaction. The replacement by a late aplite, of inclusion material, could also operate in conjunction with the previously described rim crystallization and replacement of some granodiorite.

GEOLOGIC STRUCTURE

Structure of the Metamorphic Rocks. The metamorphic rocks are completely enclosed in plutonic rocks. The large masses strike northwest and dip steeply. The accordance with the attitude of the roof rocks of the Sierra Nevada to the north suggests the larger metamorphic bodies are remnants of the original batholith roof. The name roof pendant is applied to such isolated roof remnants, on the assumption that they are protrusions of the roof down into the batholith. Some of the smaller bodies are parallel in attitude to the larger roof pendants, while others have a random orientation and are xenoliths—presumably roof fragments that were loosed into the batholith.

No major folds have been recognized, nor have any features been recognized for determining the tops of beds. Numerous minor folds a few feet in magnitude were observed, but no correlation with major features was found. Everywhere it was observed, the metamorphic layering, inferred as parallel to the original bedding, was parallel to schistosity. The apparent lack of repetition of the major metamorphic units suggests a homoclinal sequence with no major folds within the mapped area.

Igneous-Metamorphic Contacts. Sharp contacts are present along the east side of the largest pendant mass, but the lack of plentiful exposures does not warrant the statement that sharp contacts are the most plentiful.

Lit-par-lit injection zones are uncommon; but one such zone, particularly well developed, is exposed east of Hospital Rock camp (photos 9, 10). The presence of injection zones may reflect the relative nearness of the pendant root. On the east side of the largest pendant mass, the contact shows decreasing amounts of injection at higher elevations. The magma would have easier access into the metamorphic rocks near the broken root zone, while the nearly conformable wall rock at higher elevations would present a formidable barrier to intrusion. Near the Ash Mountain Park Headquarters the variation in sharpness of contacts with elevation can be seen on a small scale. The Generals Highway cuts across some narrow slivers of metamorphic rocks that are in sharp contact with the adjoining igneous rock. The small slivers can be traced down to the Kaweah River and they die out in depth.

Structure of the Plutonic Rocks. Planar structure is common locally in the granitic rocks. It is commonly shown by the sub-parallel orientation of discoid to ellipsoidal dark inclusions, and less commonly shown by schlieren and the parallelism of hornblende crystals. The local alignment of the inclusions in a plutonic body without alignment of the minerals within the inclusions, and the random orientation of inclusions in other parts of the plutons indicate the foliation is primary. Foliation is prominent only in parts of the Giant Forest, Tokopah, Potwisha, and Big Meadow plutons. The best example of the increase of foliation near a contact along the east side of the largest pendant body. Tl foliation is pronounced in the Giant Forest pluton ne the contact and becomes increasingly less prominent the east. The prominent foliation is interpreted as result of the pressure of the granitic rocks along tl pendant barrier; how much is actually due to flow, ar how much due to expansion is difficult to ascertain. Tl lack of lineation in the inclusions at this contact, however, suggests that flow was not a prominent feature i aligning the inclusions.

Lineation was only observed at two exposures. Eve where the inclusions are extremely drawn out (phot 3, 8), the inclusions are generally shaped like pancak and not prominently linear. A detailed statistical stud of the dimensions of the inclusions, however, migl disclose lineation that is not obvious in brief field exan inations of outcrops.

Joints are developed to various degrees in all th granitic masses of the mapped area. Parallelism c prominent joints over considerable areas is evident o some of the aerial photographs. Photo 11 shows an exposure of prominent parallel joints near Emerald Lak On the geologic map (pl. 1) the joint symbol was use only where prominent joints are developed over a larg area. The joints do not appear to be related to individua plutons, as the most prominent joints in the eastern par of the area transect inter-pluton contacts. The joint appear to be superimposed on the whole plutonic complex and cannot be applied to the study of the intrusio mechanics of separate plutons. Likewise, Balk's (1937 contention, that the orientation of the flow movement can be determined from the arrangement of fractur systems, does not appear to be applicable in this area.

Inter-Pluton Contacts. Most of the inter-pluton contacts are sharp, where studied by the writer. Th contact between the Giant Forest and the Potwisha plutons is gradational and is marked by an increase in dar minerals and inclusions in the Potwisha pluton. Th Potwisha quartz diorite may represent a contaminate facies of the Giant Forest pluton. The contact of th Cactus Point granite and the Elk Creek gabbro wa studied at only one exposure, and the contact wa marked by a 30- to 50-foot foliated mixed zone. Th mixed contact is interpreted as a zone of chemical reaction between the two diverse rock types.

The scarcity of gradational contacts may indicat that the succeeding intrusions came into relatively soli rocks. The sharp contacts also indicate equilibrium conditions between the chemically similar quartz-rich types with little tendency for interaction.

Abundant dikes are present near some of the contacts in particular, dikes of Big Meadow pluton material i the Giant Forest pluton. The anastamosing dikes an some isolated blocks exhibit what amounts to a mixe contact, but the individual contacts are sharp.

Mode of Intrusion of the Plutonic Rocks. The Sequoia area, though an excellent place to study some o the relations between plutons and the characteristics o individual plutons, is not well suited for a study of th mechanics of intrusion. The general massiveness of th plutonic units makes it difficult to judge the effect o later plutons on the intruded rock. The only remnant f wall and roof rocks are the pendants and scattered large xenoliths. The lack of wall rock contacts makes t particularly difficult to prove or disprove forceful njection as the mode of intrusion. The only evidence n the Sequoia area concerning forceful injection is egative. The schist shows no apparent disturbance at he contact, and there is no brecciation. The lack of recciation is also evident in the plutonic units, but f the invaded rock was plastic at the time of intrusion, isplacements caused by forceful intrusion might not e evident.

A recent paper by Noble (1952) discusses the evaluation of criteria for the forcible intrusion of magma. Noble states that the structure of the surrounding schists n the Sierra Nevada does not show how much room was made, but that the internal structure of the plutons uggests forcible injection. Ernst Cloos (1933) considers as conclusive evidence of forceful injection the ome-shaped internal structures of Sierra Nevada plutons and the absence of stoped blocks and assimilated material. No domes of foliation were found in the Sequoia area; but the good foliation along the east margin f the Sequoia roof pendant the writer interprets to ndicate upward movement or expansion along the pendant wall, with no necessity for forceful injection. After passive invasion by stoping or assimilation, later movements could align minerals and inclusions while he magma was in a plastic state. Such later movements would tend to conform to the wall rock contacts.

The plutonic complexity of the Sequoia area suggests hat in earlier work (Mayo, 1941) igneous contacts may have been missed, and that large areas that have been onsidered structural units are in actuality comprised f several granitic masses.

Assimilation along the margins of the schist pendants s best developed east of Ash Mountain Park Headquarters where small metamorphic bodies feather out into plutonic rocks, leaving wisps of weakly schistose dark material. Photos 9 and 10 show an injection zone with some assimilation.

That stoping has been active is most obviously shown by blocks of metamorphic rocks that do not conform to the attitude of the roof rocks. The largest of these blocks covers an area of approximately half a square mile. Xenoliths are present along some of the contacts and in some exposures large numbers have been liberated from lit-par-lit areas (see photos 9, 10). If the dark inclusions of doubtful origin are considered xenolithic, they also probably represent stoped material. North of Big Meadow n an area of abundant exposures, numerous blocks of Giant Forest pluton material are included in the Big Meadow pluton. One of these blocks is 100 feet across. This is one of the few areas where direct evidence was seen of one pluton stoping another. The mixed contacts resulting from the presence of many dikes may well be examples of arrested stoping, in which most of the block material is still in place.

One of the best examples of passive intrusion as opposed to forceful injection is seen on the map in the area north of Cabin Creek. Two small disconnected bodies of Big Meadow pluton material show a well-developed foliation which is coincident with the foliation of the main mass to the south. The foliation is not distorted by the intrusion of the Weaver Lake quartz monzonite as would be expected with forceful injection.

ECONOMIC GEOLOGY

The area considered in the present report is principally in Sequoia National Park and is not open to prospecting or development of mineral resources. The portion of the area that is within Sequoia National Forest has been prospected to some extent, and the Redwood Canyon area, which was only recently incorporated into Kings Canyon National Park, has also been prospected.

The only mineralization found in the plutonic rocks by the writer consists of a minor occurrence each of molybdenite and copper carbonates. The extreme rarity of quartz veins precludes much fissure-vein type mineralization.

Tactite, locally scheelite-bearing, has been developed from the calcareous metamorphic rocks, particularly in Redwood Canyon and along the North Fork of the Kaweah River. The Barrington tungsten mine, on the North Fork of the Kaweah River, contains the only scheelite in other than trace amounts that was found in the area. The workings of the Barrington tungsten mine consist of two short adits 150 feet in total length. The scheelite is contained in a garnet-pyroxene-quartz tactite. The metamorphic body that contains the tactite is a large schist xenolith near a roof pendant. In 1944, a small tonnage of ore was shipped to the Metals Reserve Company (Krauskopf, 1953). The mine was idle in 1951.

The Redwood Canyon mine, described by Jenkins (1943), consists of a 40-foot shaft, a small adit, and several trenches in a layer of garnet tactite. The tactite was worked for tungsten and copper, but also reportedly contained small amounts of silver and gold. Specimens collected at the prospect by the writer contained only traces of scheelite, but did have sparse amounts of chalcopyrite and bornite; weathered surfaces showed considerable copper carbonate staining. The mine shipped a small tonnage of high-grade ore to the Metals Reserve Company in 1943-44 (Krauskopf, 1953).

Considering the extensive outcrops of marble within the mapped area, undiscovered tactite bodies may be present, particularly in the less accessible, brush-covered areas.

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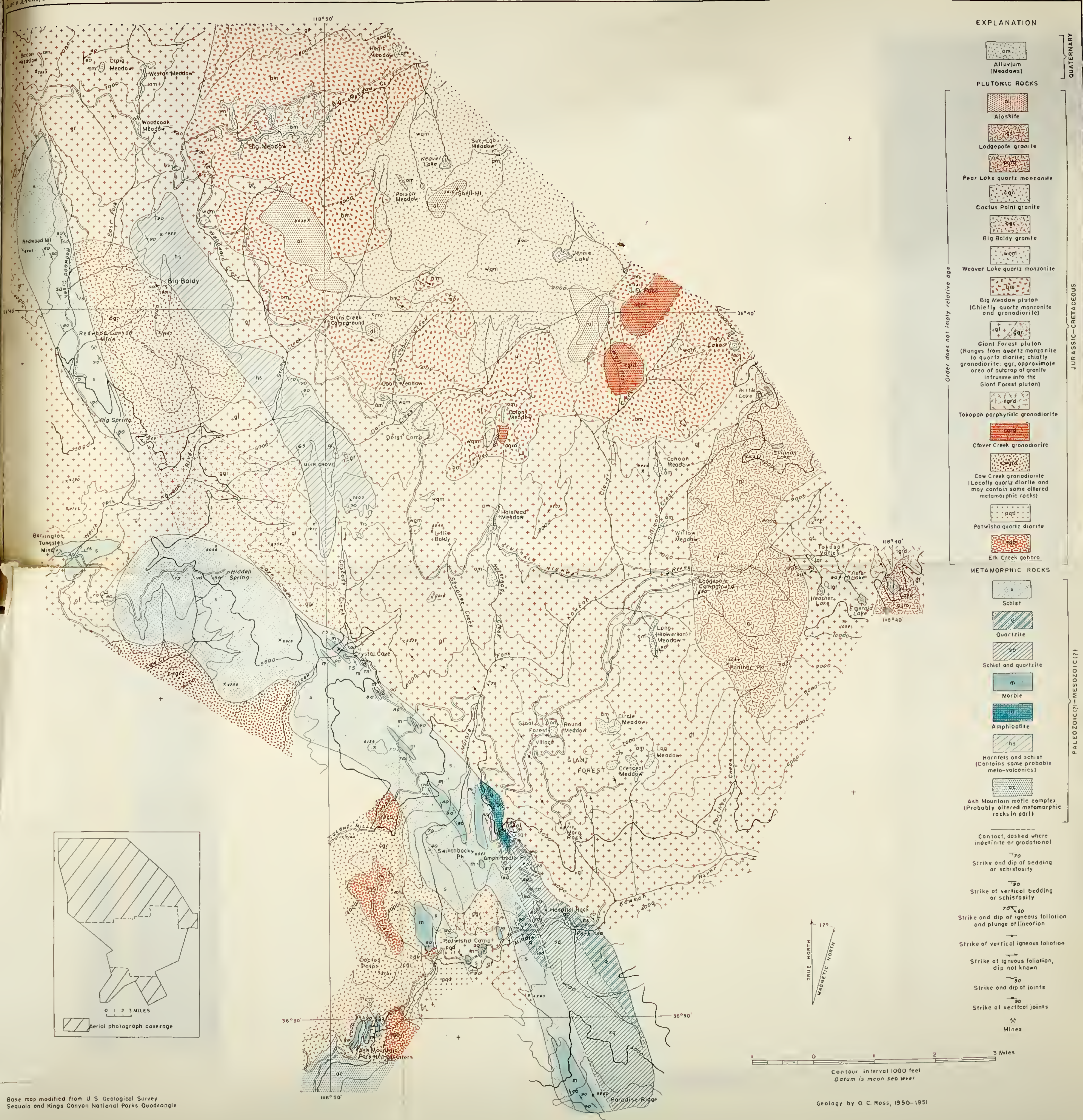
SPECIAL REPORT 53
PLATE 1



Base map modified from U.S. Geological Survey Sequoia and Kings Canyon National Parks Quadrangle

Geology by O. C. Ross, 1950–1951

GEOLOGIC MAP OF PARTS OF SEQUOIA AND KINGS CANYON NATIONAL PARKS, TULARE COUNTY, CALIFORNIA